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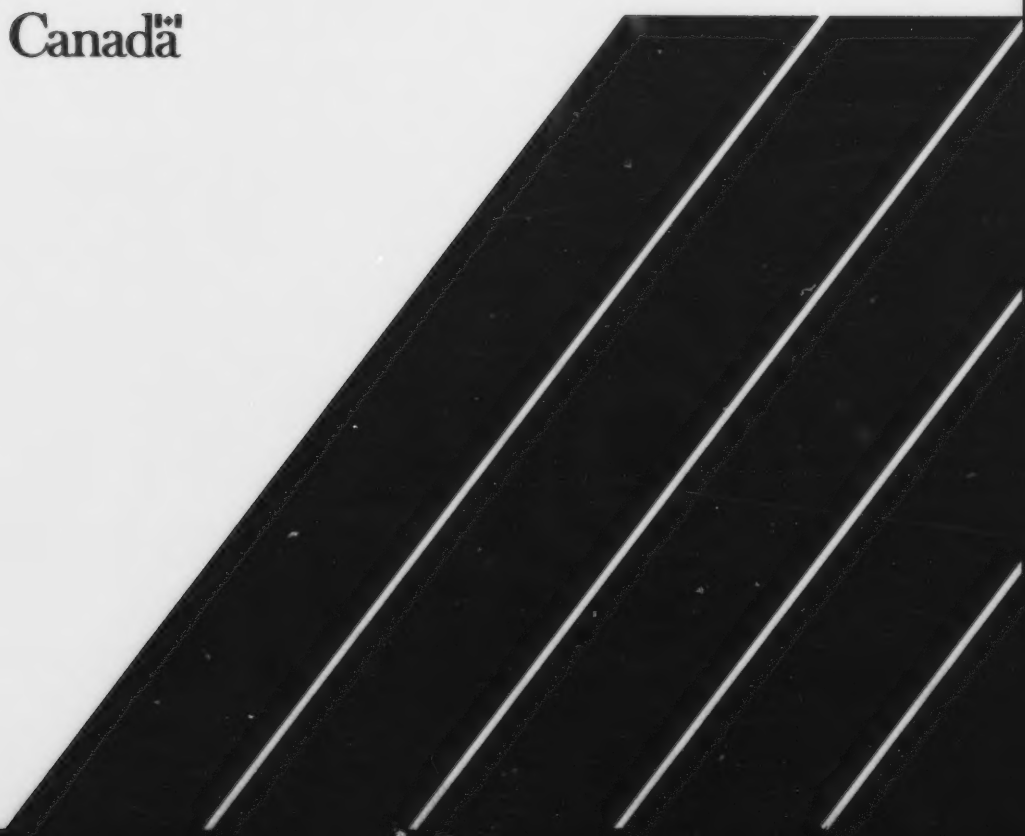
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SURFACE ENVIRONMENTAL RESEARCH AT THE
ELLIOT LAKE LABORATORY
A COMPILATION OF PAPERS

Y.M. BOUCHER, N.K. DAVE AND T.P. LIM

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SURFACE ENVIRONMENTAL RESEARCH AT THE ELLIOT LAKE LABORATORY
A COMPILATION OF PAPERS

Y.M. Boucher*, N.K. Dave**, T.P. Lim⁺

FOREWORD

Increasing concern is being expressed on the environmental problem of uranium and base metal mine/mill tailings. In the early seventies mine/mill waste management research was initiated at the Elliot Lake Mining Research Laboratory to study revegetation and reclamation of the tailings as a means of reducing the environmental impact.

In more recent years, extensive biogeochemical and contaminant migration pathway research has been undertaken to understand all processes leading to generation, migration and release of contaminants from the reactive tailings into the biosphere and hydrosphere. This compilation consists of Abstracts of all extensive surface environmental research carried out by the Elliot Lake Laboratory in the following six categories:

1. Reclamation/revegetation.
2. Microbiology.
3. Hydrogeochemistry.
4. Contaminant migration.
5. Biological pathways.
6. Analytical instrumentation.

An overall review of these technical categories is required to provide a basis for formulating comprehensive interdisciplinary research to investigate in detail, the longterm behaviour of reactive mine tailings. Two major tailings research programs:

- a) National Uranium Tailings Program (NUTP); and
- b) Mine Environment Neutral Drainage (MEND), formerly known as Reactive Acid Tailings Stabilization Program (RATS)

have been undertaken to develop techniques that will enable the uranium and base metal mining industry to abandon acid generating tailings in a cost effective and environmentally acceptable manner.

Key words: Environmental impact; Waste disposal.

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RECHERCHES SUR L'ENVIRONNEMENT DE SURFACE EFFECTUÉES AU LABORATOIRE
D'ELLIOT LAKE
COMPILATION DE DIVERS ARTICLES

Y.M. Boucher*, N.K. Dave** et T.P. Lim⁺

PRÉFACE

Le problème environnemental que constituent les résidus d'extraction et de préparation des minerais d'uranium et de métaux non précieux suscite de plus en plus d'inquiétude. Des recherches sur la gestion des déchets de mines et d'usines de préparation ont été entreprises au début des années 1970 au Laboratoire de recherche minière d'Elliot Lake, afin d'étudier dans quelle mesure la restauration de la couverture végétale et la récupération des métaux dans les résidus permettraient de réduire l'impact sur l'environnement.

Plus récemment, d'importantes recherches sur la biohydrogéochimie et sur les mécanismes de migration des contaminants ont été entreprises en vue d'élucider tous les processus à l'origine de la production, de la migration et de la libération dans la biosphère et l'hydrosphère des contaminants provenant de résidus réactifs. La présente compilation renferme des résumés de tous les importants travaux de recherche sur l'environnement de surface qui ont été réalisés dans les six domaines suivants au Laboratoire d'Elliot Lake:

1. Récupération des métaux dans les résidus/restauration de la couverture végétale

2. Microbiologie
3. Hydrogéochemie
4. Migration des contaminants
5. Mécanismes biologiques
6. Appareillage d'analyse.

Ces domaines techniques devront faire l'objet d'une étude globale qui permettra d'établir une base à partir de laquelle des recherches interdisciplinaires exhaustives pourront être effectuées en vue d'examiner en détail le comportement à long terme des résidus miniers réactifs. Deux importants programmes de recherche sur les résidus, soit

- a) le Programme national de recherches sur les résidus d'uranium et
- b) le Programme de neutralisation des eaux de drainage dans

l'environnement minier (NEDEM), anciennement connu sous le nom de Programme des résidus acides réactifs, ont été entrepris dans le but de mettre au point des techniques qui permettront à l'industrie de l'extraction des minerais d'uranium et de métaux non précieux de se débarrasser des résidus acidogènes d'une façon à la fois rentable du point de vue économique et acceptable du point de vue environnemental.

Mots clés: impact sur l'environnement, élimination des déchets.

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RECLAMATION/REVEGETATION

1. VEGETATION OF MINE WASTE EMBANKMENTS IN CANADA.

by D.R. Murray - Internal Report MR 71/31-ID, March 1971.

Abstract - Reclamation concepts of tailings and waste embankments are presented, including soil physical, chemical and microbiological parameters, climatic conditions, selection of vegetation species, surface preparation, planting methods and overall land rehabilitation program.

2. FACTORS AFFECTING REVEGETATION ON URANIUM MINE TAILINGS IN THE ELLIOT LAKE AREA. PART 1: PHYSICAL CONDITIONS.

by D.R. Murray - Internal Report MR 71/104-ID, October 1971.

Abstract - Physical parameters affecting revegetation are: climate, topography, surface and soil conditions. Each factor is discussed as it relates to revegetation of uranium mill tailings in the Elliot Lake area. Tailings physical and chemical conditions are to be amended prior to successful vegetation trials.

3. REVEGETATION PROBLEMS OF MINE TAILINGS IN NORTHERN ONTARIO

by D.R. Murray - Internal Report 71/113-LD, 1971.

Abstract - The physical and chemical problems facing the revegetation of mill tailings are briefly discussed. Samples of the tailings and slides are shown in explaining the problems.

4. ENGINEERING ASPECTS OF RESEARCH INTO RECLAIMING MINE WASTE EMBANKMENTS

by Z. Eisenstein and N.R. Morgenstern - Internal Report 72/4-LD, 1972.

Preface by D.F. Coates - Increasing concern is being expressed by society on the damaging effects of mining to the external environment. One of the aspects that requires attention is the large areas that are occupied by waste dumps and tailings. The reclamation of such areas, so that the land can be used for other purposes, requires basic knowledge in the areas of geotechnical engineering and agronomy.

The relationships between the various technical factors influencing the appropriate solution in any one area are not at the present time clear. A review of these relationships is being undertaken to provide a basis for formulating comprehensive interdisciplinary research. Among other things, it will be necessary to gather case histories of pertinent experience in industry and ultimately to investigate in detail the longterm behaviour of selected waste embankments in Canada.

5. FACTORS AFFECTING REVEGETATION OF URANIUM TAILINGS IN THE ELLIOT LAKE AREA
PART 2: CHEMICAL CONDITIONS

by D.R. Murray - Internal Report 72/55, May 1972.

Abstract - Chemical and physical properties of uranium tailings from Elliot Lake were examined to characterise them in relation to a soil. The results indicated that the tailings is not a soil. The high free acid and potential acidity, the high moisture retention capacity, and the tie-up of nutrients are the most pronounced problems.

Preliminary tests - calculation of lime requirement, influence of mulch and root growth observation - are described.

6. RECLAMATION CONFERENCE AND WESTERN FIELD TRIP

by D.R. Murray - Internal Report 72/72, June 1972.

Abstract - The conference, "Reclamation of Disturbed Land Areas", held 17-18 April, 1972 at Cecil Green Park, University of British Columbia, showed that extensive reclamation work was in progress in that Province. The problems facing the reclamer were basically climate, topography and soil texture. It was also noted at the conference that concerns regarding poor dissemination of information and education of the public were important.

The field trip to mines in Southern British Columbia emphasized the extreme site conditions. Testing was still in the trial stage but the results were best where reclamation staff were employed.

7. GROWTH CHAMBER EXPERIMENTS - PROGRESS REPORT 1972.

by D.R. Murray - Internal Report 73/16, February 1973.

Abstract - The germination and seedling vigour of fourteen grasses were tested on fresh uranium tailings in comparison to limestone treated weathered tailings. The results showed that fresh tailings were more suitable for plant growth from the test viewpoint. The usefulness of growth chamber facilities for this work is discussed.

8. FIELD TRIALS 1972 - PROGRESS REPORT

by D.R. Murray - Internal Report 73/19, February 1973.

Abstract - Field trials initiated in 1972 were designed to test depth of cultivation, fertilization systems and plant species. Plots of 20 ft. x 20 ft. with one replicate indicated that deep cultivation of 6 inches was necessary on coarse uranium tailings and that frequent fertilization of 100 lb/ac/month was five to ten times better than a single application at seeding time of 600 lb/ac. The plant species did not show significant differences.

This is an initial evaluation following vegetation establishment. Subsequent examinations in the following years and adequate replication will be necessary for conclusive evaluation.

9. MINERALOGY OF WASTE MATERIALS AS INFLUENCING PLANT GROWTH AND SOIL DEVELOPMENT

by D.R. Murray - Internal Report 73/33, February 1983.

Abstract - Effective plant growth depends on adequate soil environment. Mineralogy is one important aspect that cannot be omitted. The availability of nutrients depends on the capacity of the soil clays to hold ions from being leached out of the soil. This article explains how clay minerals perform this and other benefits for plant growth. The mineralogical information outweighs the analytical costs when soil amendments are required.

10. AN APPROACH TO REVEGETATION OF MINE WASTES

by D.R. Murray and G. Zahary - Internal Report 73-68, May 1973.

Abstract - In the Elliot Lake area there are approximately 1000 acres of abandoned tailings from mining operations. They present dust, water seepage, and aesthetic problems. Revegetation is considered to be a possible solution.

Initial attempts to establish vegetation were made on an empirical basis with limited success. This has been followed by a more methodical approach with emphasis being laid on the following factors: i) climate and site condition; ii) physical and chemical properties of the waste; iii) plant growth trials; iv) field trials.

Investigations indicated that the most critical factors affecting revegetation were: 1) prevailing temperate climate; 2) unstable surface with no capacity for aggregation; 3) poor drainage with high moisture retention in fines and low moisture retention in coarse tailings; 4) high acidity; 5) agriculturally inert with no cation exchange capacity.

A selection of grass and legume species were used in plant growth trials and the following limitations were identified: 1) seeding dates would be critical; 2) frequent fertilization would be required; 3) the depth of the root zone would be determined by the depth of cultivation; 4) one tailings basin would require several different treatments.

Legumes were eliminated and five grass species were selected for field testing on small test plots. Vegetation has been established and maintained for two seasons on coarse tailings. Research is still in progress to establish vegetation on the fine tailings.

11. INFORMATION FOR POTENTIAL CONTRACTORS - REVEGETATION PROJECT 1974-1977.

by D.R. Murray - Internal Report 73-153, October 1973.

Abstract - One of the objectives of the Department of Energy, Mines and Resources is 'environmental protection and improvement involving the minimization of adverse effects on the external environment'.

Within this objective a project has been formulated with the goal of: 1) identifying Canadian mine wastes by their physical and chemical properties; and 2) identifying the vegetative growth response on these wastes of seeded and volunteer species. It is envisaged that with this information the minimum

management requirements to obtain suitable plant growth can be identified. This would reduce the great expense in money and time now required to reclaim solid mine wastes. Although each waste is unique in many respects, there are similarities which need not be established by testing in each case. Research is approximately 25% of the total cost of reclamation. Selective research to reduce repetitive or futile work would in turn reduce total cost to industry.

It is estimated that \$225,000 to \$300,000 over a three year period will be required to achieve these objectives for major waste sites across Canada. A rough division of the budgeted amount would be contracts of \$8,000 to \$10,000 per study per year, with universities, consultants, and other organizations participating. In the third and final year the research will be grouped according to waste material for preparation of a reclamation manual.

This project is a multidisciplinary investigation which will include industry, university staff and graduate students in Crop Science, Soil Science, Microbiology and Plant Physiology.

12. RECLAMATION - A CHALLENGE TO OPEN PIT MINING OPERATIONS IN CANADA

by G. Zahary, D. Murray and B. Hoare - Internal Report 74/19, Jan. 1974.

Abstract - The need to rehabilitate mine sites is now recognized by both the public and industrial sectors in Canada. This is a comparatively recent perception requiring new as well as greater use of existing technology. Canada produces a wide variety of mineral wastes. The mines are typically medium to large sized and are located in sparsely populated regions. Climate and land forms vary widely across the country. These considerations have an important bearing on the extent of reclamation that is possible and desirable.

In general, a desirable objective of reclamation in open pit mining is "to maximize the benefits to be obtained from the Nation's natural resources by developing and implementing reclamation procedures to protect the environment without seriously restricting the effective development of the mineral resources".

Four major areas offer a challenge to this objective in open pit mining: 1) reclamation of spoil piles in open pit operations; 2) reclamation of tailings disposal areas; 3) reclamation of rock dumps; and 4) reclamation of open pits following the cessation of mining operations.

In Canada revegetation is considered to be one of the most desirable

forms of reclamation and it has the additional advantage of providing surface stabilization for fine materials such as tailings. The ease with which a vegetative cover can be established depends on a broad range of factors, not the least of which are the physical and chemical properties of the waste materials. Research on highly siliceous and acidic tailings is currently under way and methodical procedures for establishing cover crops are being developed.

The stability of waste dumps, tailings dams and pit slopes is related to reclamation. The structural aspects have been reviewed, and further studies are in progress with a view to establishing recommended procedures to assure long-term stability.

13. INFORMATION FOR POTENTIAL CONTRACTORS - REVEGETATION PROJECT 1974-1977
YEAR 2

by D.R. Murray and D.F. Coates - Divisional Report 74/111, Sept. 1974.

Abstract - One of the major objectives of the Department of Energy, Mines and Resources is to "ensure the effective use of mineral and energy resources available in Canada for the present and future benefit of the nation by improving the means of exploration, mining, extraction, processing, transportation suitable for resource development and usage", and at the same time, "minimizing the adverse effects on the environment".

Within these objectives, a project has been formulated with the goal of reducing the cost of mineral production by supplementing research data into engineering systems for mine waste disposal designs. Part of the project is concerned with the reclamation of the land affected by the operation which includes stabilization of mine wastes. Both stability and broader reclamation objectives are achieved largely through appropriate revegetation.

Owing to the great variety of unknown factors affecting current attempts to revegetate mining related disturbed land, the intention of the Department is to compile a pedologic inventory of mine wastes. This will serve to reduce the time and expense required to achieve successful reclamation. The objects of the inventory are: 1) to identify Canadian mine wastes by their physical and chemical properties; and 2) to provide information on the characteristics which are limiting for vegetation establishment and growth. Although each waste pile or dump is unique in many

respects, there are similarities which can usefully be identified. Research costs are currently estimated as 25% of the total cost of reclamation. This cost to the community can be reduced by coordinated data gathering and communication.

It is estimated that some \$250,000 over a three-year period will be required to achieve the above objectives. Contracts for this work of \$10,000 to \$20,000 per study per year will be jointly made with industry (including mining companies, consultants and private research laboratories), universities and other organizations. In the third and final year the research results will be compiled according to a waste embankment classification and made available to the public.

This project is a multidisciplinary investigation which will include industry and universities requiring knowledge in crop science, soil science, microbiology, and plant physiology.

14. PROGRESS REPORT ON BLACK DISCOLOURATION OF VEGETATION GROWN ON SULPHIDE-CONTAINING URANIUM TAILINGS.

by D.R. Murray, D. Moffett & D. Shearer - Report MRP/MRL 76-78(TR), 1976.

Abstract - Vegetation is accepted as the most effective means of mine tailings reclamation. Research on establishing vegetation on sulphide containing uranium tailings at Elliot Lake has developed a healthy vegetation cover. The self-sustaining nature of the vegetation is limited by the annual occurrence of black discolouration of plant tissue. This report describes the studies initiated to determine the cause of this discolouration. Suspected Cu and/or Fe toxicity were discounted.

15. VEGETATING THE ELLIOT LAKE URANIUM MINE TAILINGS

by D. Murray and D. Moffett - Report MRP/MRL 76-114(J), August 1976.

Abstract - The vegetation of pyritic uranium tailings has been demonstrated using a surface application of limestone, 2.24 kg/m^2 (10 tons/acre), to neutralize acidity and chemical fertilizers to compensate for the lack of nutrients and the very low cation exchange capacity. No supplemental organic matter or top soil has been used. A total of 26 grasses, legumes and annuals

were seeded in field plots 3 m x 6 m (10 ft x 20 ft). Six of the grasses and three of the legumes have persisted over 4 growing seasons and their suitability in a vegetation program is assessed. The basis for species selection was herbage yield, percent ground cover and field observations. Reed Canarygrass was the most successful species, but a mixture of Creeping Red Fescue with Red Top or Kentucky Bluegrass is preferred due to their superior sod-forming abilities. The performance of the legumes was poor and their incorporation in seed mixtures is judged not worth while.

16. RECLAMATION BY VEGETATION

by D.R. Murray - Report MRP/MRL 76-166(OP), December 1976.

Abstract - Canada has a long history of mining and thereby accumulating mining wastes. Little has been known about the ability of wastes to sustain vegetation. In 1974 CANMET initiated a three year study on the potential of vegetation for reclaiming mine wastes.

This report outlines the results of that investigation and identifies the problems associated with establishing vegetation. It describes the type of wastes and their properties with the aim of providing the mine operator adequate information about capabilities and limitations of vegetation methods.

17. RESEARCH ON TAILINGS DISPOSAL AT ELLIOT LAKE

D. Moffett - Report MRP/MRL 76-169(OP), December 1976.

Abstract - The current research on uranium tailings being carried out at CANMET's Elliot Lake Laboratory is briefly outlined. Two areas are singled out: vegetation and effluent control. A recipe for the revegetation of uranium tailings has been developed to provide a self-sustaining grass cover. A survey has been made of the uptake of radioactivity by grasses which indicates that the level in grasses remains very low. The research on effluent control is geared towards "at-source" solutions. Studies on an abandoned tailings area are conducted to provide information on the mechanisms by which acid is produced within tailings and is carried to the surrounding watercourses. An experiment has been designed, in cooperation with Rio Algom Ltd., to test the effects of various tailings covers: vegetation, woodchips

and alluvial till on the quality and quantity of seepage from tailings. Microbiological studies are aimed at determining the role of bacteria in producing acid, and at finding bacteriacides to control the rapid oxidation of pyrite. Sulphate reducers may be useful in treating acidic seepage.

18. UPTAKE OF RADIOISOTOPES BY VEGETATION GROWING ON URANIUM TAILINGS

by D. Moffett and M. Tellier - Report MRP/MRL 77-6(J) Revised, Feb. 1977.

Abstract - An investigation was carried out on the uptake of several long-lived radioisotopes by grasses growing on uranium tailings. Field plots of creeping red fescue (Festuca rubra L.), reed canarygrass (Phalaris arundinacea L.), redtop (Agrostis alba L.) and climax timothy (Phleum pratensis L.) which have been growing for four years, were sampled in this study. The tailings and the plant tissue were analyzed for uranium, thorium, radium-226, lead-210 and polonium-210. Sedimentation within the tailings area gave two zones: one of sands and one of slimes. The slimes contained significantly more radium-226, lead-210 and polonium-210 than the sands. There was no difference in uptake behaviour by grasses growing in the sands and those growing in the slimes. Creeping red fescue (Festuca rubra L.) showed an anomalous uptake of lead-210, but other than this, all four grass species showed similar uptake behaviour. Only uranium and radium-226 were significantly higher in the grasses from the tailings than the control.

19. LAND RECLAMATION AT CANADA'S URANIUM CAPITAL

by D. Moffett - Report MRP/MRL 77-19(J), February 1977.

Abstract - Some of the current research on the vegetation of uranium tailings at CANMET's Elliot Lake Laboratory is outlined. A recipe for the vegetation of the tailings has been developed which requires a five-year program. A means of assessing the success of the grass cover by measuring plant yield and percent ground-cover is described. Reed Canarygrass and Red Top are the most vigorous species. A survey of the uptake of radioactivity by grasses is included and this indicated that uranium and radium-226 are concentrated to a significant degree, although this does not appear to present any increased danger of radioactive exposure to man or environment.

20. THE INFLUENCE OF URANIUM MILL TAILINGS ON TREE GROWTH AT ELLIOT LAKE, ONT.
by D.R. Murray - Report MRP/MRL 77-80(J), July 1977.

Abstract - A four-year study was carried out to determine the ability of coniferous trees to aid in the reclamation of uranium tailings at Elliot Lake. Five species were planted: white cedar, white spruce, jack pine, scotch pine and red pine. Over 570 bare root, two-year old seedlings were planted on bare tailings and in areas of established grasses. A further division was made between areas of coarse and fine tailings.

Overall survival and growth of the trees have been far below expectations from previous experience with several varieties of grasses. The criteria for assessment have been percent survival and yearly growth as determined by plant height. Pine was superior with 68% survival when planted in bare coarse tailings, 45% for vegetated coarse tailings, and 34% for vegetated fine tailings. Cedar had the worst survival rates at 49%, 14% and 7%, respectively. No species survived on bare fine tailings.

The survival and growth of the coniferous trees have been related to species, environmental conditions and tailings properties.

21. TOUR OF COAL MINE RECLAMATION SITES IN WESTERN GERMANY AND THE UNITED KINGDOM, OCTOBER 1977.

by D.R. Murray - Report MRP/MRL 77-134(TR), December 1977.

Abstract - The highlights of a tour of coal mine reclamation sites in Western Germany and the United Kingdom that was organized by the Coal Association of Canada are described. The mining methods include bucketwheel excavation with conveyor belts as the major equipment in Germany. Soil texture and space, however, limit the use of this equipment in the United Kingdom. Reclamation procedures are well organized with selective soil removal and placement. An innovative method of top-soil placement as a slurry is described. Attitudes of governments and industry are to return the land to equal or better productivity than existed before mining. The value of this experience to Canada is an example of what can be accomplished with detailed preplanning for reclamation.

22. RECLAMATION OF LOWER WILLIAMS LAKE TAILINGS AREA OF DENISON MINES LIMITED
by D. Murray, B. Webber and E. Larocque - Report MRP/MRL 78-1(J), 1977.

Abstract - The reclamation of a 2 hectare uranium tailings area is described. The exposed tailings of 1.4 hectares were capped with glacial till and vegetated with grasses and legumes. The water running through the tailings was diverted around the tailings in a lined ditch and treated with sodium hydroxide and barium chloride. Difficulties occurred in placing the till capping because of the low bearing strength and the uneven surface of the tailings. This led to varying thicknesses of till and the need for manual labour in some areas. Total reclamation costs were \$32,200 with vegetation establishment costs at \$13,700 per hectare. This report provides a record of work for use in assessing the long term suitability of these treatments.

23. PROPOSAL FOR 5 YEAR MINE WASTE RECLAMATION PROGRAM 1978-1983
by D.R. Murray - Report MRP/MRL 78-40(TR), April 1978.

Abstract - Reclamation of mine wastes has received increased attention over the past 10 years. However, progress has been somewhat piecemeal with little interaction between groups reclaiming individual sites. From the work of CANMET there appear to be several areas where reclamation can be made more effective.

This proposal aims to concentrate studies on 5 areas needed to advance reclamation technology: design of waste disposal sites, soil amendments, mechanical handling, crop selection and water-vegetation relationship. Technology transfer to industry would be achieved through reports, on-site demonstrations and seminars.

A 5-year program is proposed using existing CANMET staff augmented by contract funds. The total cost is estimated at \$850,000 including \$150,000 contributed by industry on a cooperative basis.

24. SOIL PROFILE DEVELOPMENT IN VEGETATED URANIUM TAILINGS
by D.R. Murray - Division Report MRP/MRL 81-126(J), September 1981.

Abstract - The reclamation of uranium mill tailings has concentrated on

reducing surface erosion, improving aesthetics and reducing the environmental impact of seepage and groundwater contamination. The most promising long-term solution has been establishing a vegetation cover directly on the tailings material. This report characterizes the soil profile of areas vegetated for 0, 3, 8 and 10 years to assess the rate of soil development and the stability of the profile that exists. The vegetation program has produced a rapid build up of organic matter in the top 10 cm of tailings where natural microbial populations have begun to flourish. The C:N ratio, however, is high and the actual profile depth shallow. Some recommendations on fertilizer application and crop management are made to assist in developing an ecologically viable soil. The impact of vegetation and soil profile on hydrological quality is considered.

25. STUDIES ON TREE GROWTH ON ELLIOT LAKE URANIUM TAILINGS

by D.R. Murray - Division Report MPR/MRL 82-14(J), January 1982.

The stabilization of tailings in the Elliot Lake area of Ontario using a grass/legume sward, has been studied since 1970. Surface stabilization has been successful. A soil profile is developing under this vegetation. Efforts are now being turned on the long-term stability of the cover and its impact on water quality in the surrounding area.

In 1974, coniferous trees were planted on vegetated and unvegetated areas. These were assessed in 1977 and 1981. Over the 8-year period of growth the survival rates were 0%, 18% and 28% for cedar, pine and spruce, respectively, on previously vegetated sites. The low survival rates are attributed primarily to the high competition from the established grass cover and to disease. Survival was better on unvegetated areas, but growth was much slower there in the first four years. Trees were planted in 1981 in a vegetated area and the grass was cut to permit exposure of the seedlings to sunlight, without completely removing the ground cover.

From 1970 to 1973 while stabilization progressed across the tailings, deciduous trees volunteered. Sites of various ages were selected and the tree growth was assessed in 1981. The distribution of height and diameter classes of the volunteer population is studied. They consisted mainly of birch, poplar and willow. Height classes ranged from 1 to 300 cm while the diameter classes ranged from 0 to 5.5 cm. From the 8-year old to the 11-year old site

it appears that the trees are as a group growing larger, but not necessarily generating a young understory. The information on tree growth is being assessed to determine the factors favourable to natural encroachment so that these conditions may be included in procedures for establishing a tree cover after grass stabilization has occurred.

We believe that trees, as the climax vegetation, will have a very significant impact on soil hydrology and water use. We believe this will be markedly different from that of a grass/legume stand. By combining the sciences of Agronomy, Forestry, Chemistry and Hydrology, we hope to examine the difference between a forest and grass stand as it affects effluent water quality.

26. TREE GROWTH STUDIES ON URANIUM MILL TAILINGS

by D.R. Murray and M. Turcotte - Division Report MRP/MRL 82-19(TR), 1982.

Abstract - Coniferous trees planted in 1974 and deciduous species that have volunteered since 1970 on uranium mill tailings that had been stabilized to varying degrees using limestone and vegetation were evaluated. Their survival and growth rates were compared with those from other investigations.

Competition for light appears to be a major contributor to mortality. Differences in soil moisture conditions under a tree stand as compared to those under a grass sward are potentially significant enough to affect the tailings hydrology and effluent contamination.

Recommendations include planting seeds of deciduous species or deciduous and coniferous seedlings on strips of freshly disturbed tailings. The disturbed strips would provide reduced competition for the initial year and assist in tree survival.

The planting of block stands of coniferous or deciduous trees would be useful for evaluating the hydrological impact of the trees as compared to the present grass sward.

27. GUNNAR MAIN TAILINGS: FIELD OBSERVATIONS

by D. Murray and H. Horn-Johnson - Division Report MRP/MRL 82-120(TR) 1982

Abstract - The Gunnar uranium mill tailings near Uranium City, Saskatchewan

was the site of a number of vegetation experiments. The progress of some of these studies was assessed by the authors in August of 1982 to obtain a perspective for future work. The effects of quick and slow release fertilizer, grass seeding and hummock transplantation were evaluated and are reported. Slow release fertilizer continued to show its effect while seedlings and transplants indicated problems due to drought and blowing sands from the unstable surface. Several suggestions for vegetating the entire tailings are discussed.

28. SOIL PROFILE DEVELOPMENT IN VEGETATED URANIUM TAILINGS

by D.R. Murray - Division Report MRP/MRL 82-147, December 1982.

Abstract - A promising long term solution to uranium tailings reclamation has been the establishment of vegetation directly on the waste material. The soil profiles of areas vegetated for 0, 3, 8 and 10 years are characterized as to the extent of soil development. The characteristics are compared with the visually interpreted soil profile. Organic matter content is presently the best analytical judge of soil development. Vegetation procedures have produced a build-up of organic matter in the top 10 cm of tailings where natural microbial populations flourish. The C:N ratio is high and the profile depth shallow suggesting the need for additional fertilizer applications.

29. SURVIVAL POTENTIAL OF VEGETATION COVER ON URANIUM TAILINGS

by T.P. Lim, N.K. Dave, Y. Boucher and A.J. Vivyurka
Division Report MRL 88-43(TR), March 1988.

Abstract - A field test was conducted regarding survival potential and prediction modelling of vegetation cover on uranium tailings after a natural disaster such as flood or forest fire.

The Nordic Main uranium tailings area was rehabilitated by vegetation cover, starting in 1978, and was maintained and fertilized until 1982. Within a few years a definite soil-like profile developed consisting mainly of decomposed organic matter.

In 1985, a flood destroyed about 20% of the cover, and vegetation is slowly growing back to generate a new cover without human intervention.

Two years after the flood, biomass samples were collected for comparison between the damaged and undamaged areas. Results showed that the wet weight regrowth of biomass from the damaged area is 4.6 to 5.9 times lower than from the undamaged area, and the dry weight of the regrowth is 2.4 to 5.3 times lower than from the undamaged area. The biomass on the undamaged area can retain 1.3 to 1.5 times more water than the damaged area.

The area will be re-assessed to establish the time required for the vegetation to recover to the same condition as the undamaged area.

MICROBIOLOGY

30. SOIL MICROBIOLOGY IN RELATION TO THE REVEGETATION OF MINE TAILINGS

by N. Purych - Divisional Report 74/116, July 1974.

Abstract - Difficulty has been experienced in establishing self-sustaining vegetation on mine tailings. Soil micro-organisms are essential to self-sustaining systems. The physical and chemical properties of uranium tailings in the Elliot Lake area are assessed and the habitat requirements of micro-organisms are described. Requirements of pH, organic matter substrate, nutrients, water and oxygen are not likely to be met by untreated tailings. Liming, fertilization and the growth of vegetation for a period of several years are likely to correct some of these difficulties but drainage of excessively wet tailings is advisable. The biological cycling of nutrients, improved soil structure, provision of humus and improved plant growth can be expected to result from the establishment of a microbial community on revegetated tailings. Most soil micro-organisms are naturally dispersed and will invade any environment which is within their biological limits of tolerance. Healthy plant growth and a build up of organic matter would indicate favourable conditions for microbial life. Experimental artificial inoculation to speed up natural invasion may be worthwhile but should be considered only after natural invasion has been assessed. After microbial activity comparable to that of a similar natural community has been established, fertilization of revegetated tailings may be discontinued but it should be followed by careful observation to detect signs of nutrient deficiency.

31. A MICROBIOLOGICAL APPROACH TO THE ACIDIC MINE TAILINGS PROBLEM

by R.G.L. McCready - Report MRP/MRL 75-114(TR), December 1975.

Abstract - The acidity from mine wastes of the Elliot Lake area is estimated to be 560 tons per year. Although there are no national estimates for total acid production in Canada, the U.S. Department of the Interior estimates that four million tons of acid are released into their environment per year. To date the exact mechanism of biological acid production from metal sulfides is not known. However, the acid production in mine wastes greatly hinders attempts at revegetation due to the adverse conditions in which the microflora of the plant rhizosphere must become established.

Attempts to prevent acid production in abandoned wastes tend to be prohibitively expensive, e.g., \$8,000/acre for an asphalt coating. The most viable approach at present appears to be revegetation at a cost of \$2500/acre over a five year period, provided the vegetation becomes self-sustaining by that time.

Thus microbiological research is required to: 1) Determine whether or not a normal microflora is developing in revegetated areas. 2) Assess the potential use of biocides and develop testing procedures for such agents to prevent further environmental damage. 3) Search for specific thiobacillus parasites or bacteriophages as a means of controlling thiobacilli. 4) Test the feasibility of using sulfate-reducing micro-organisms such as Desulfovibrio desulfuricans or Bacillus cereus as means of removing SO_4^{-2} and iron from acid waste seepage.

32. THE METABOLISM OF THE THIOBACILLI

by R.G.L. McCready - Report MRP/MRL 76-38(TR), March 1976.

Abstract - Recently the recovery of metals by biological leaching has become more prevalent. A basic understanding of the metabolism of the micro-organisms involved in this process is essential. Further, these organisms contribute to acid production in the waste material of sulphide ores mined by conventional techniques.

The genus *Thiobacillus* has been recently reclassified into three groups dependent on their chemical composition and metabolic characteristics. Two members of the genus, T. ferrooxidans and T. thiooxidans are involved in metal leaching. The important biological mechanisms in the leaching process are considered to be CO_2 fixation, energy transfer, and the oxidative pathways for iron and sulphur.

33. BIOLOGICAL CONTROL OF THIOBACILLI

by R.G.L. McCready - Report MRP/MRL 76-59(TR), April 1976.

Abstract - A literature review has been carried out in order to define and assess various biological means of controlling the acid producing *Thiobacilli* associated with pyritic mine wastes. Four possible control schemes have been

explored including Caulobacter, Bdellovibrio Bacteriovorus, Rotifers, and bacteriophages.

The most feasible approach seems to be the use of bacteriophages as they are high specific, self-perpetuating, lethal parasites which present no adverse environmental effects on the surrounding biosphere.

34. MICROBIAL ASSESSMENT OF THE VEGETATED TEST PLOTS ON THE PYRITIC URANIUM TAILINGS IN THE ELLIOT LAKE AREA

by R.G.L. McCready - Report MRP/MRL 76-161(TR), November 1976.

Abstract - A microbiological assessment of the vegetated test plots of the Nordic Tailings in the Elliot Lake area was carried out during the 1976 growing season. Total microbial counts indicate that sufficient numbers and diversity exists in the present microflora to accomplish nutrient recycling and support a self-sustaining vegetative cover. Preliminary experiments indicate that cellulose degradation is occurring, but further studies are required to assess the nitrogen-fixing capabilities of the microflora.

35. A MICROBIOLOGICAL INVESTIGATION OF URANIUM TAILINGS WATER SAMPLES

by R.G.L. McCready - Report MRP/MRL 77-5(TR), January 1977.

Abstract - A microbiological investigation of water samples taken from an uranium tailings area was undertaken as part of the tailings effluent water quality study at the Elliot Lake Laboratory. Although no correlation between the microbial counts and the chemical composition of the waters can be made at this time, several interesting observations were noted.

Thiobacillus ferrooxidans is distributed throughout the entire tailings area and appears to be most active at the air-water interface. Further T. ferrooxidans was shown to survive in waters with pH values greater than 4.0 to 4.5. All samples examined had variable numbers of heterotrophic organisms, with Gram negative aerobes being the most predominant group of bacteria.

36. THE EFFECTS OF SOLVENT EXTRACTION ORGANICS ON THIOBACILLUS FERROOXIDANS

by R.G.L. McCready - Report MRP/MRL 77-44(OP), March 1977.

Abstract - Recent interest in the use of bacterial leaching as a means of recovering metal values from low grade sulphide ores has resulted in numerous technological questions which require basic research prior to implementation of various processes in the mining industry. The present study on the effects of solvent extraction organics on Thiobacillus ferrooxidans is part of the ongoing bacterial leaching program at CANMET.

T. ferrooxidans is capable of growth and metabolism in the presence of 30% saturation of the aqueous medium with the various reagents tested. The majority of these reagents inhibit bacterial growth by chemically attacking the lipid component of the cellular cytoplasmic membrane and if present in sufficient concentrations may destroy membrane integrity and cause cell lysis. In contrast the extractant, Alamine 336, acts by complexing the inorganic metabolites which are required by cellular growth.

The effluent from the solvent extraction cycle may be recycled for leaching provided the organic concentration in the aqueous phase is reduced to 30% saturation or less and the pH of the leaching solution is maintained at pH 2.0

HYDROGEOCHEMISTRY

37. CORE SAMPLING OF THE ELLIOT LAKE TAILINGS

by D.R. Murray and L.A. Melis - Internal Report 73/170, November 1973.

Abstract - Three core samples were taken to obtain a profile of a uranium tailings pond. The change in physical and chemical properties with depth of tailings were studied both in the field and laboratory in a cooperative study between Mines Branch Elliot Lake Laboratory and Rio Algom Research and Development.

The identification of two distinct fractions of tailings (fine and coarse) and their influence on the chemical properties of the waste was made. Acidic conditions caused by the oxidation of pyrite existed on the surface and up to a depth of 2 to 3 feet on fine tailings and 15 to 18 feet on coarse tailings. This acidity appears to be a surface and aeration effect. Revegetation is similarly a surface treatment that should reduce the total detrimental effect on the environment.

Sampling was done to a depth of 20 feet but results indicated that sampling to 3 to 5 feet would be adequate for revegetation purposes.

38. MEASUREMENT OF RADIUM-226 IN WATER FROM TEST WELLS IN A URANIUM MINE TAILINGS AREA

by T.P. Lim and N.K. Dave - Report MRP/MRL 78-70(TR) - Sept. 1978.

Abstract - Eighteen 1.5 in. diameter piezometers were installed during 1973 in the West Arm tailings area for water quality testing purposes.

Three piezometers were chosen for consistency tests of Ra-226 concentration in the water. This information will be useful to decide on future sampling technique, sample preparation and routine water quality monitoring for Ra-226.

Sample preparation and sample preservation should be done carefully to avoid self-absorption during the Ra-226 alpha-spectroscopy analysis.

Two piezometers showed erratic results in the Ra-226 analyses and the slow response time suggested that the wells were clogged. The third piezometer gave consistent Ra-226 concentrations of about 160 pCi/L and a fast response time showed that fresh tailings water recharged the well quickly.

39. PROPOSAL FOR THE APPLICATION OF THE GAMMA-RAY METHOD FOR MONITORING THE MOVEMENT OF RADIONUCLIDES IN URANIUM TAILINGS PONDS

by V. de Korompay - Division Report MRP/MRL 80-72(TR), December 1979.

Abstract - Gamma-ray logging method is recommended for monitoring the movement of radionuclides in uranium tailings ponds.

The essence of the Gamma-ray logging is presented in this report.

Factors affecting the true radioactivity determination, such as formation density, porosity, water saturation, dilution of pore water, radioactive water in the borehole, borehole conditions and effect of Gamma-ray sonde are discussed.

Special well construction for Gamma-ray logging is recommended.

40. SUBSURFACE HYDROLOGY AND GEOCHEMICAL EVOLUTION IN INACTIVE PYRITIC TAILINGS IN THE ELLIOT LAKE URANIUM DISTRICT, CANADA

by J.A. Cherry, R.J. Blackport, N. Dubrovsky, R.W. Gillham, T.P. Lim, D. Murray, E.J. Reardon and D.J.A. Smyth - Report MRP/MRL 80-121(OP), 1980. Also in Proc. Symp. on Uranium Mill Tailings Management, Fort Collins, CO, November 1980.

Abstract - The first two phases of a continuing investigation of the chemical composition and movement of pore water in inactive tailings in the Elliot Lake uranium district of Ontario were conducted in 1979 and 1980. The tailings in this district are produced by the acid-leach process and are neutralized to pH levels of 8 to 10 before discharge from the mills. Nests of piezometers were installed at numerous locations in two tailings areas, the Nordic Main and Nordic West Arm. These areas received tailings during the late 1950's and during the 1960's and were recently vegetated in preparation for abandonment. A single nest was installed in an older area of inactive tailings, the Lacnor tailings, with incomplete vegetative cover.

In the Nordic Main tailings the depth to the water table varies spatially from less than 1 m to about 10 m. Annual fluctuations of the water table are generally between 0.5 and 1.5 m. The depth-to-water table in the Nordic West Arm tailings varies from 1 m to 3 m, with less fluctuation than the Main tailings. Flow in the Nordic Main tailings is consistently downward, whereas in the West Arm, areas of downward, upward and lateral flow occur. In the three tailings deposits, oxidation of pyrite is causing the original neutralized pore water to be gradually replaced by acidic pore water that

mobilizes radionuclides and heavy metals in the tailings. Sampling of pore water above the water table at three sites on the Nordic Main tailings indicates that nearly complete acidification of the unsaturated zone has occurred. In an area of the West Arm where the tailings are coarse-grained and have downward groundwater flow, the entire thickness of the tailings has become acidic but in other areas where finer-grained tailings occur or results indicate that in order to minimize the long-term production of acidic pore water in abandoned tailings, reclamation of the tailings surface will have to be done in a manner that greatly reduces the flux of oxygen into the unsaturated zone.

41. PARTICLE SIZE DISTRIBUTION OF URANIUM TAILINGS CORE SAMPLES

by D.R. Murray and M. Turcotte - Report MRP/MRL 81-13(TR), January 1981.

Abstract - Core samples were taken by the University of Waterloo from the Nordic tailings area. This was in conjunction with a joint research program between CANMET and the University of Waterloo. The study was to determine the hydrogeochemistry of the tailings disposal system. This particle size distribution and separation was one contribution by CANMET.

Samples were dried at Waterloo and returned to Elliot Lake. Dry screening was done using a Tyler testing sieve shaker using up to 100 grams of sample. Of the 8 screens used, the smallest was No. 325 or 45 micrometers (μm) opening. The material passing this screen was further described using erimetry. The results are reported on a percent passing or percent smaller than screen sizes or particle sizes. The fraction remaining on each screen section was stored separately when reasonable amounts were present.

Eight screen sizes used in the Ro-Tap sieve shaker. Shaking was done for 15 minutes using an automatic timer. For the material passing the No. 325 screen (PAN) a small representative portion was spread on a glass slide that was pre-treated with a film of non-drying adhesive. Excess sample material was shaken off and the remaining mono-layer of particles examined for size distribution by erimetry. Results of both the dry screening and erimetric sizing are reported. Error in the erimetry values have a potential of being up to 20%.

42. CHEMICAL AND RADIOISOTOPE DISTRIBUTION PROFILES IN AN ABANDONED URANIUM TAILINGS PILE

by N.K. Dave, T.P. Lim and A.J. Vivyurka - Division Report MRP/MRL 81-109 (OP,J), Sept. 1981. Also in Proc. 4th Symp. on Uranium Mill Tailings Management, Fort Collins, CO, October 1981. Session 4, p. 343.

Abstract - Chemical and radioisotope distribution profiles were studied in the solid fraction of an abandoned uranium tailings site at Elliot Lake, Ontario, Canada. The tailings, with a thickness of 7-10 m, over an area of 85 hectares, were deposited approximately 10-20 years ago on a layer of black peaty material which overlays deposits of permeable glacio-fluvial sand.

Geohydrochemical investigations of this tailings area have been ongoing since 1978. The radioisotope profile study was conducted on various sites. Solid core samples, collected with split spoon and modified Shelby tube samplers at various depths, were analyzed for various chemical and radioisotope constituents. The results indicated two distinct zones of stratification, an upper zone, where the constituents were uniformly distributed and a lower zone, near the peat-tailings interface, which showed increasing concentration with depth. Within the peat layer the concentration decreased rapidly with no significant levels of contamination penetration below the peat layer being observed, through the samples were limited. The pH profile showed that the top 5 m of the tailings have been oxidized with an average soil pH of 3.8 compared to 6 underneath it. The groundwater hydrology of the system was observed to be complex. Various hypotheses of the tailings profile development are discussed based on the combined segregation and settling process of fine fraction and geohydrochemical interaction of solid and liquid phases.

43. CHEMICAL AND RADIOISOTOPE STRATIFICATION IN AN ABANDONED URANIUM TAILINGS PILE

by N.K. Dave, T.P. Lim and A.J. Vivyurka - Division Report 81-110(OP,J), 1981. Also in Proc. Int. Conf. on Radiation Hazards in Mining: Control, Measurement and Medical Aspects, Golden, CO, October 1981.

Abstract - Chemical and radioisotope stratification studies were carried out in an abandoned uranium tailings pile at Elliot Lake, Ontario, Canada. The tailings, with an average thickness of 7 m over an area of 16 hectares, were deposited approximately 20 years ago on a layer of black peaty material which

overlays deposits of permeable glaciofluvial sands.

Geohydrochemical investigations of this tailings area have been ongoing since 1978. The radioisotope profile study was conducted on three adjacent sites. Solid core samples, collected with a split spoon sampler at various depths, were analyzed for various chemical and radioisotope constituents. The results indicated 2 distinct zones of stratification; an upper zone, where the constituents were uniformly distributed, and a lower zone, near the peat-tailing interface, which showed increasing concentration with depth. Within the peat layer, the concentration decreased rapidly with no significant levels of contaminant penetration below the peat layers observed, though the samples were limited. The pH profile showed that the top 5 m of the tailings have been oxidized, the average soil pH in this zone was 3.4 compared to 5.8 underneath it. The groundwater hydrology of the system was observed to be complex showing downward and lateral flow in the dry season and lateral and upward flow during the spring and periods of heavy rainfall.

The results are discussed in terms of a model based on the combined segregation and settling process of the tailings fine fraction, and the geohydrochemical interaction of the solid and liquid phases.

44. HYDROGEOCHEMICAL EVOLUTION OF AN INACTIVE PYRITIC URANIUM TAILINGS BASIN AND RETARDATION OF CONTAMINANT MIGRATION IN A SURROUNDING AQUIFER

by N.K. Dave, T.P. Lim, A.J. Vivyurka, N. Dubrovsky, K.A. Morin, D. Smyth, R.W. Gillham and J.A. Cherry - Division Report MRP/MRL 82-34(OP,J), 1982. Also in Proc. Int. Symp. Management of Wastes from Uranium Mining and Milling, Albuquerque, NM, May 1982, pp. 215-229.

Abstract - At the inactive Nordic tailings impoundment in the Elliot Lake uranium mining district, Ontario, hydrogeochemical investigations are being conducted to determine the effects of pyrite oxidation on the chemistry of pore water in the tailings and on the subsurface leaching of metals and radionuclides from the tailings. The tailings have been inactive for more than a decade and in recent years the tailings surface has supported a cover of grass. Originally the pH of the tailings pore water was about 7, but since the tailings became inactive, near-surface pyrite oxidation resulting from exposure to oxygen and water has caused the pH of pore water above the water table in the tailings to decline to the range of 1.5-3, with an associated rise in dissolved iron, sulphate, metals and radionuclides to high

concentration levels. The direction of net subsurface water movement in the tailings is downward, and therefore, the acidic pore water gradually moves downward through the tailings into the permeable sandy groundwater zone beneath the tailings. The rate of this downward migration is controlled by the rate of downward pore water flow and by geochemical processes, primarily those that consume acid, such as reactions involving residual lime-derived carbonate minerals and reactions involving iron and aluminum.

In most of the tailings area, the zone of low-pH pore water has not yet reached the bottom of the tailings. In one of the areas where it has passed all the way through the tailings, a plume of tailings-derived water with high iron and sulphate concentrations has moved in the sand aquifer a horizontal distance of 400 m beyond the tailings dam. Although the iron-sulphate plume has moved this far, the front of the low pH water is still close to the toe of the tailings dam. Three years of monitoring has established that the low-pH front is advancing in the sand aquifer at a rate that is less than 1 percent of the groundwater velocity. The rate of acid-front advance is severely retarded because of pH neutralization caused by the dissolution of trace amounts of carbonate minerals in the sand. Although the plume segment beyond the low-pH front has high concentrations of iron and sulphate derived from the tailings, it does not contain hazardous levels of radionuclides or heavy metals, because these constituents are either insoluble or strongly adsorbed at neutral pH.

A narrow zone, near the bottom of the tailings, was observed to have high solid-phase concentrations of various chemical and radioisotope constituents. This is attributed to the settling of fines in the bottom layer containing precipitates of gypsum and metal hydroxides, and co-precipitation and adsorption of trace metals and radionuclides from the residual process water.

Investigations of the conditions on the surface of the tailings indicate that there is a slight accumulation of Ra-226 isotope in the vegetation with a vegetation to tailings concentration ratio (CR) of 0.03 on dry matter basis and a transfer coefficient of 6×10^{-6} . No significant variation between plant species or significant accumulation in the seeds were observed.

45. OVERVIEW OF "HYDROGEOCHEMICAL INVESTIGATION OF AN INACTIVE PYRITIC URANIUM TAILINGS BASIN, ELLIOT LAKE, ONTARIO"

by N.K. Dave - Division Report MRP/MRL 82-44(OP), April 1982.

Abstract - In Canada alone there are approximately 120 million tonnes of uranium tailings spread over an area of 635 hectares. It is expected that by the time the present uranium ore reserves are mined, there will be approximately 1 billion tonnes of uranium tailings which will require proper management technology, without much human involvement in the form of continuous treatment and monitoring, in limiting the release of contaminants to the environment. At present, research activities are directed towards existing inactive pyritic uranium tailings piles to investigate their hydrogeochemical evolution and patterns of contaminant migration to the surrounding environment in order to evaluate various abandonment schemes.

In pyritic uranium tailings, the oxidation of pyrite and other iron sulphides produces highly acidic conditions within the tailings with the subsequent leaching of the tailings material resulting in highly acidic pore water containing significant concentrations of iron, sulphate, heavy metals and radionuclides. The migration of such a poor quality tailings water, either by surface run-off or sub-surface groundwater, can lead to serious deterioration in the quality of adjacent natural water systems.

Hydrogeochemical investigations of an inactive pyritic uranium tailings basin have been on-going for the past 4 years at the Nordic Mine tailings site in Elliot Lake, Ontario, Canada. The major elements of study are: 1) tailings area hydrogeology; 2) the zone of active pyrite oxidation; 3) geochemical characteristics of the tailings pore water; 4) soil gas and solid phase composition of the tailings material; 5) migration of contaminants as a surface run-off and as a sub-surface seepage in the surrounding aquifer; and 6) interaction of the vegetative cover with the tailings material in relation to uptake of radioisotopes and other contaminants.

46. COLUMN PERMEABILITY AND FLOOD LEACHING TESTS ON VARIOUS MIXTURES OF HEAP LEACHED CRUSHED ROCK AND IRON HYDROXIDE-GYPSUM SLUDGE FROM AGNEW LAKE MINES - PRELIMINARY REPORT

by N.K. Dave, T.P. Lim and L. Heymann - Division Report MRP/MRL 82-80(TR), June 1982.

Abstract - Permeability and column leaching tests under flooded conditions of various leached crushed rock and iron hydroxide-gypsum sludge sample mixtures from Agnew Lake Mines were conducted to determine their effluent quantity and quality as a function of time. It was found that the permeability of the sludge-rock mixtures was an order of magnitude lower than that of the pure crushed rock. The leaching tests indicated that under flooded conditions the pH of the effluent remained fairly constant with time. No evidence of continued sulphur oxidation was observed in the tests and the effluent quality was primarily governed by the presence and dissolution of gypsum in the sample material. Ra-226 was dissolved from the crushed rock, its concentration being moderated by hydrogen and sulphate ion concentrations. The Ra-226 concentration in the leachate decreased with volume throughput.

47. GEOPHYSICAL AND BIOHYDROGEOCHEMICAL INVESTIGATIONS OF AN INACTIVE SULPHIDE TAILINGS BASIN, NORANDA, QUEBEC, CANADA

by N.K. Dave, T.P. Lim, R. Siwik and R. Blackport - Division Report M&ET/MRL 86-99(OP,J), July 1986. Also in Proc. Nat. Symp. on Surface Mining, Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, Dec. 1986. p. 13.

Abstract - Geophysical and biohydrogeochemical investigations were carried out at an inactive copper-zinc mine tailings site, Waite Amulet, near Noranda, Quebec, Canada. Geophysical investigations consisted of seismic, electromagnetic conductivity and electrical resistivity surveys to determine the thickness of the layers above bedrock and to map conductivity variations within the tailings and the immediate outlying area. Biohydrogeochemical investigations consisted of installing multilevel piezometer nests to determine groundwater flow patterns and porewater chemistry, obtaining solid core samples and characterizing for physical, chemical and mineralogical parameters, and iron oxidizing and sulphate reducing bacterial counts.

The geophysical survey indicated a bedrock ridge extending under the tailings from the northeastern outcrop which may act as a porewater boundary layer. The survey also indicated a 2 to 20 m clay layer underlying the main tailings dam. Preliminary results of the saturated zone porewater chemistry have indicated three major zones of high electrical conductivity varying between 1000 to 12,000 μS and pH between 3.4 to 8. Lower pH and high metal and sulphate concentrations were obtained in a shallow zone near the water

table. With depth, the concentration of metal and sulphate ions decreased and pH increased below the water table. The underlying clay layer is relatively impervious and most of the seepage from the tailings is probably exiting from the sides of the impoundment dam.

In the unsaturated zone, the pH increased with depth from 3 to 6. Bacterial analysis showed a strong presence of Thiobacillus Ferro-oxidans in the upper 2 m of tailings (8000 to >100,000 MPN/g). Sulphate reducing bacteria were not detected in a majority of samples below the water table.

48. HYDROGEOCHEMICAL INVESTIGATION OF THE REACTIVE TAILINGS AT THE WAITE AMULET TAILINGS SITE, NORANDA, QUEBEC

by R.Siwik and N.K. Dave - Proc. Canadian Mineral Processors Operators Conf., Ottawa, January 1987.

Abstract - The National Reactive Tailings (RATS) program is a cooperative industry-government effort to develop practical techniques for closure of reactive tailings areas. This paper summarizes the RATS program objectives and areas of research, and details the Noranda/CANMET project on the Waite Amulet tailings.

Geophysical and biohydrogeochemical investigations were carried out at an inactive copper-zinc mine tailings site, Waite Amulet, in Noranda, Quebec. Geophysical investigations consisted of seismic, electromagnetic conductivity and electrical resistivity surveys to determine the thickness of the layers above bedrock and to map conductivity variations within the tailings and the immediate outlying area. Biohydrogeochemical investigations consisted of installing multilevel piezometer nests to determine groundwater flow patterns and porewater chemistry, obtaining solid core samples and characterizing for physical, chemical and mineralogical parameters, and iron oxidizing and sulphate reducing bacterial counts.

The geophysical survey indicated a bedrock ridge extending under the tailings from the northeastern outcrop which may act as a porewater boundary layer. The survey also indicated a 2 to 20 m clay layer underlying the main tailings dam. Preliminary results of the saturated zone porewater chemistry have indicated three major zones of high electrical conductivity varying between 1,000 to 12,000 μS and pH between 3.4 to 8. Lower pH and high metal and sulphate concentrations were obtained in a shallow zone near the water table. With depth, the concentration of metal and sulphate ions decreased and

pH increased below the water table. The underlying clay layer is relatively impervious and most of the seepage from the tailings is probably exiting from the sides of the impoundment dam.

In the unsaturated zone, the pH increased with depth from 3 to 6. Bacterial analysis showed a strong presence of Thiobacillus ferro-oxidans in the upper 2 m of tailings (8,000 to >100,000 MPN/g). Sulphate reducing bacteria were not detected in a majority of samples below the water table.

Studies are currently underway dealing with monitoring oxygen diffusion, metal dissolution and transport, and oxidation control techniques.

CONTAMINANT MIGRATION

49. ASSESSMENT OF TAILINGS DISPOSAL AND EFFLUENT CONTROL SYSTEMS OF ELDORADO NUCLEAR'S BEAVERLODGE OPERATION

by D. Moffett - Report MRP/MRL 75-119(TR), December 1975.

Abstract - The tailings disposal and effluent system of Eldorado Nuclear's Beaverlodge operation is described. Radium-226 is the single contaminant of importance in flows into Beaverlodge Lake. Levels of this radioisotope commonly exceed the desirable limit of 3 pCi/L. Potential methods for reducing radium-226 loadings into Beaverlodge Lake are suggested. The contribution of abandoned or inactive mines to the problem is unclear.

50. ATTENDANCE AT THE INPLACE LEACHING AND SOLUTION MINING SHORT COURSE, LAKE TAHOE, NEVADA, NOVEMBER 10-14, 1975.

by R.G.L. McCready, Report MRP/MSL 75-259(C), November 1975.

Abstract - The course emphasized the problems associated with biological or chemical hydrometallurgical extraction of metal values. People involved in current leaching operations pointed out the problems and recommended possible corrective measures.

M. Anderson predicted that 50% of the copper produced in 1980 would be obtained by hydrometallurgical means.

Research is now being intensified to explore the use of leaching technology for a variety of metals (Al, Au, Ag) and for the recovery of all metals from a given orebody regardless of their percentage content.

51. TAILINGS DISPOSAL, HAZARDS AND TREATMENT IN THE ELLIOT LAKE AREA

by D. Moffett and D.R. Murray - Report MRP/MRL 76-9(TR), January 1976.

Abstract - The present state of inactive uranium tailings in the Elliot Lake area is outlined, and their environmental impact briefly discussed. Methods of rehabilitation are reviewed with emphasis on revegetation and effluent treatments. Cost estimates are given for revegetation, effluent control and restricting access.

52. THE DISPOSAL OF SOLID WASTES AND LIQUID EFFLUENTS FROM THE MILLING OF URANIUM ORES

by D. Moffett - CANMET Report 76-19, July 1976.

Abstract - Current Canadian practice in the milling of uranium-bearing ores commonly involves fine grinding followed by acid leach and ion exchange. The acid leach may be followed instead by solvent extraction. Alkaline leaching had been done, and in situ bacteriological leaching is of interest.

Tailings disposal operations are necessary and create environmental problems. Uranium-mill wastes are unique because of their radioactivity. Some of the radioisotopes present may require an individual control procedure. Radium-226 is particularly important because it is the most hazardous of all isotopes found in the tailings. Acid and heavy-metal removal is conventionally done by the addition of lime, but other means are available, such as with limestone, sodium hydroxide, ammonia, silicon alloys or by sulphide precipitation.

Modifications to unit operations in the mill process may be required to produce more acceptable effluents. Increased water recycling may be necessary to meet regulatory standards.

53. PRELIMINARY INVESTIGATIONS OF AN INACTIVE URANIUM-TAILINGS BASIN

by D. Moffett - Report MRP/MRL 76-25(TR), February 1976.

Abstract - The results of preliminary field investigations of the water associated with the acid-generating Nordic uranium-tailings basin are described. Subsurface water, seepage and contaminated surface-water were sampled and analyzed in the summer of 1975. Acidity and total dissolved solids (TDS) are proposed as good water-quality indicators. Thorium is being leached from the tailings although its impact on the environment is unknown.

54. ACIDITY AND pH: USEFUL INDICATORS OF WATER POLLUTION?

by D. Moffett - Report MRP/MRL 76-34(OP), February 1976.

Abstract - pH is defined and related to the hydrogen ion concentration of a number of acids. Acidity is defined and its use as a quality indicator in

field samples is explained. Both pH and acidity analyses are necessary to characterize natural waters because of the oxidation and hydrolysis which takes place within them.

The determination of acidity is also applied to solid tailings samples where it is found that the acidity correlates with the pyrite content of the tailings.

55. REVIEW OF WASTE DISPOSAL AT CANADIAN URANIUM MINES

by D. Moffett - Report 76-43(J), March 1976.

Abstract - The waste disposal practices of the uranium mining industry are unique on account of the low-level radioactivity of the wastes. Eleven thousand tons of solid wastes are disposed of daily, and the bulk of these are impounded in conventional tailings areas. In addition, there are almost 1000 acres of inactive or abandoned tailings areas. All of these areas are sources of low-level radiation, 0.1 to 1.0 mR/hr. Uranium mills use up to 300 gallons of fresh water per ton of ore milled. The process effluents, in addition to mine water and surface drainage, require continuous treatment for radium-226 removal. This is accomplished by the addition of barium chloride, and the treatment systems generally perform adequately. Surface drainage also requires lime additions to neutralize acidity and precipitate heavy metals. The mills practise recycling of mine water and limited reuse within the mill circuits. However, discharges from tailings basins are not presently recycled.

Alternate means of disposal other than surface impoundment are presently under consideration. These include deep-lake disposal and increased use of the tailings in mine backfilling.

56. ENVIRONMENTAL ASPECTS OF THORIUM

by D. Moffett - Report MRP/MRL 77-43(OP), March 1977.

Abstract - Thorium is present in many uranium ores. The uranium to thorium ratio for some Canadian mining camps ranges from 14 to 0.33. There are six thorium isotopes which occur in uranium and thorium ores although only one of these, ^{232}Th , is present in any mass. All six isotopes contribute to the

radioactivity in the ore and in the tailings. The typical contributions of the six isotopes to the total thorium activity in the tailings are: ^{234}Th (2%), ^{230}Th (77%), ^{231}Th (<0.1%), ^{227}Th (4%), ^{232}Th (8.5%) and ^{228}Th (8.5%). These contributions coupled with the maximum permissible concentrations in water (MPC_w) of the isotopes identify ^{230}Th , ^{232}Th and ^{228}Th as the isotopes of concern. From an environmental viewpoint, the present surface tailings containment areas do not ensure the containment of the thorium within the tailings area in the long term. The thorium is in a state which is very susceptible to leaching and redissolution. The effluent from active operations contains very low levels of the thorium isotopes because of its neutral or weakly basic pH. Acidic seepage flows exceed the MPC_w for ^{230}Th but this is markedly reduced by the practice of lime additions. The precipitated thorium is deposited in a lagoon where its ultimate stability is difficult to assess. Because ^{232}Th has an extremely hazardous radium isotope ^{228}Ra , which may be present in significant activities in the effluents from mines with a low uranium to thorium ratio, concern is expressed for the adequacy of the current surveillance procedures for radium.

57. RADIOLOGICAL INVESTIGATIONS OF AN ABANDONED URANIUM TAILINGS AREA

by D. Moffett and M. Tellier - Report MRP/MRL 77-54(J), April 1977.

Abstract - Tailings have been accumulating in the Elliot Lake area since mining started some twenty years ago. The impoundment areas have been designed to contain solids, and a clear and neutral overflow was considered satisfactory practice. However, acid generated in the tailings by oxidation of pyrite can escape along with any heavy-metal solutes through embankments that are usually porous to some degree. Now experience has shown that these areas, some of which have been idle for over a dozen years, release acids in seepage and overflows to an unacceptable degree. The tailings outflows are neutralized wherever required to raise the pH to 8.5 and to precipitate heavy metals that may be in solution.

This neutralization will have to be continued indefinitely, unless a better remedy is found (Lord 1976).

An investigation is underway of one 16 hectare (ha) pyrite-containing uranium tailings area to determine what happens to the radioactive elements within the tailings area. The analysis of solid samples showed the activities

of ^{226}Ra , ^{210}Pb and ^{210}Po are lower than could be accounted for by their radioactive decay since disposal. Uranium and thorium also have been significantly leached out of the tailings surface. The collection and analysis of water samples from beneath the water table revealed two classes of water: a low-acid class (<1000 ppm acidity) and a high-acid class. The acidity of the water was correlated to the degree of weathering of the pyrite in the surface layers of the tailings. The high-acid water samples generally contained high concentrations of radioisotopes especially ^{210}Pb , ^{232}Th , ^{230}Th , ^{228}Th and uranium. These isotopes are leached from the tailings by acid percolating through the tailings. In contrast, the low-acid water samples in the tailings area contained only concentrations of ^{226}Ra which, if released untreated, would exceed water quality criteria.

Seepage samples were also monitored and analyzed, and may exceed desirable water quality criteria for ^{226}Ra and ^{210}Pb if not treated.

58. DETERMINATION OF THE IN SITU VERTICAL PERMEABILITY OF MINE BACKFILLS AND WASTE MATERIALS.

by V. de Korompay - Report MRP/MRL 77-96(J), December 1976.

Abstract - The "Twin Rods" and the "Measuring Electrodes" permeameters have been developed to measure the in situ vertical permeability of hydraulic mine backfills and waste materials.

The developed instruments are based on the electrical conductivity of porous material and the operating principles eliminate the basic short-comings of the tracer technique. The permeameters measure the vertical permeability of the unconsolidated materials without disturbing the original deposition sequence of the fill or waste.

The operating principles, construction of the testers and the measuring and evaluation procedure are presented. Special problems associated with the application of the measuring technique are discussed.

The reliability of the permeameters has been established by measuring simultaneously the permeability of practically the same material using the two developed instruments and a tube type permeameter. The results of the experiments, conducted in underground stopes and uranium tailings ponds, have established that the reproducibility of the measurements of the permeameter is about $\pm 5\%$.

The field tests have indicated that the permeameters are inexpensive and practical tools for in situ investigation of porous materials and they perform well in underground stopes where space and mobility are restricted.

The instruments have potential application in connection with other technical problems, such as: a) determination of infiltration capacity of soils, b) Investigation of cemented mine backfills, c) Evaluation of the effectiveness of soil densification, consolidation and dewatering methods, and d) Simultaneous determination of the permeability of individual porous zones and fractures.

59. URANIUM MINING AND MILLING: SURVEY OF PRESENT WASTE MANAGEMENT PRACTICES
by D. Moffett - Report MPR/MRL 77-108(TR), August 1977.

Abstract - The mining and production of a uranium concentrate (yellowcake) in Canada for the past 30 years has resulted in 100,000,000 tons of solid wastes occupying an area of over 2000 acres in six different locations. The mining and milling of uranium-bearing ores results in four types of waste: 1) waste rock, 2) mine water, 3) process effluents, and 4) solid wastes (tailings). Liquid effluents appear to be the most serious waste disposal problem from operating mines and mills, and the chemicals added in the milling process are of particular concern. The solid wastes represent a problem both on account of their magnitude and their radioactivity. On abandonment, the containment of the radioactivity is of most concern because of the hazards of long-lived radioisotopes in liquid effluents. The present practice of barium-chloride additions and retention of the precipitates is, at best, an interim solution. The blowing of dust and bleak and barren appearance of the tailings can be solved by establishment of a healthy vegetative cover.

Site-specific factors, such as the presence of pyrite in the ore at Elliot Lake, seriously intensify the scope of the problem.

60. THE INFLUENCE OF RAIN ON THE QUALITY AND QUANTITY OF THE EFFLUENT AT THE WEST ARM TAILINGS AREA

by N.K. Dave and T. Lim - Report MRP/MRL 79-23(TR), December 1978.

Abstract - The quality and quantity of the effluent from the West Arm uranium

tailings area was measured as a function of time, before, during and after a short rainfall of 0.71 cm. The results indicate that while the effluent pH remains unaltered, its resistivity and dissolved Ra-226 concentration show different behaviours in relation to the effluent flow rate pattern. For a period of eighteen hours commencing at the beginning of the rain and continuing after the rain, the total load of dissolved Ra-226 and the total effluent volume increased by factors of 4.25 and 2.54 respectively over those of the pre-rain background values for the same length of time.

61. EFFECT OF SURFACE TREATMENT OF TAILINGS ON QUANTITY AND QUALITY OF EFFLUENT

by D.R. Murray and D.N. Okuhara, Report MRP/MRL 79-21(TR), March 1979.

Abstract - Reclamation of mine wastes has concentrated recently on the establishment of a vegetative cover. Main problem areas with pyritic, uranium mill tailings have been the control of wind and water erosion, improvement of aesthetic appearance, and control and treatment of effluent water, both seepage and runoff. Much research has been described and ideas put forth in the literature and at reclamation meetings. The ability of vegetation to perform these three functions has been questioned. There is no contention about the first two but the third item has been controversial. Does vegetation affect the quantity and/or quality of the effluent water? This study shows how surface treatments of sawdust, gravel, vegetation and no treatment influence the quality and quantity of the effluent. Sawdust maintains high effluent volume with low contamination levels. The bare tailings has reduced effluent but with a great deal of contamination. Gravel and vegetation have maintained reduced effluent with low contamination. Recommendations for 1979-81 studies are given to verify interpretations made on the 1975-78 data.

62. DETERMINATION OF THE RELATIVE DISCHARGE RATE FROM A URANIUM MINE TAILINGS POND BY WATER LEVEL MEASUREMENTS

by V. de Korompay - Report MRP/MRL 79-25(TR), January 1979.

Abstract - A simple practical method using water level measurements only has been developed to determine the effectiveness of the revegetation or other

selected materials as a seepage reducing agent for uranium mine tailings ponds.

The effluence, consequently the rate of surface and subsurface water contamination around the tailings pond is directly proportional to the water head difference existing between the water tables inside and outside the pond.

The method uses, for the evaluation, water level measurements taken before and after revegetation or taken simultaneously under revegetated and barren sections of the pond. Effluent rate variation of $\pm 1\%$ can be detected with the measuring technique. For this reason the method is suitable for monitoring the fluctuation of the contamination rate from abandoned uranium mine tailing ponds.

The method can predict the performance of the revegetation or other selected seepage reducing material before the commitment of any large expenditure.

63. SURFACE STABILIZATION: WASTE MANAGEMENT DEMONSTRATION STUDY - PROGRESS REPORT 1978/79

by D.R. Murray - Division Report MRP/MRL 80-12(TR), February 1980.

Abstract - Research into development of a method of surface stabilization of sulphide containing uranium tailings in the Elliot Lake area has been conducted since 1971. A method was found that when tested over 5 years appeared to be quite satisfactory for large scale implementation.

This report describes the application of the recommended method in a field situation in conjunction with some hydrologic and chemical studies on seepage water contamination of the surrounding groundwater and streams. The problem encountered in implementation is discussed as experienced by the contractor and the author.

64. ANALYSIS OF THE HYDRAULIC PERFORMANCE OF A LYSIMETER TEST PIT SYSTEM

by V. de Korompay - Report MRP/MRL 80-17(TR), September 1980.

Abstract - A lysimeter pit system has been installed to evaluate the effect of the different surface treatments of tailings on quality and quantity of effluent, but the underflow and the evaporation from the pit were

inconsistent.

For this reason it was necessary to analyze the lysimeter pit operation in order to recommend a trouble shooting method and a rehabilitation procedure.

65. GROUND WATER MONITORING AND CONTAMINANT OCCURRENCE AT AN ABANDONED TAILINGS AREA, ELLIOT LAKE, ONTARIO

by R. Blair, J.A. Cherry, T.P. Lim and A.J. Vivyurka - Division Report MRP/MRL 80-85(J), July 1980. Also in Proc. 1st Int. Conf. on Uranium Mine Waste Disposal, Vancouver, May 1980, Chapter 29, p. 411.

Abstract - The first phase of an investigation of the chemical composition of subsurface water and the hydrochemical processes in and near the abandoned Nordic tailings at Elliot Lake, Ontario, was conducted in 1979. The Nordic area, which covers 85 hectares with an average thickness of 10 m and overlies deposits of permeable glaciofluvial sand, contains 15 million tonnes of tailings with 4-7% pyrite. Nests of standpipe piezometers installed at three locations on the tailings indicate that seepage through the tailings is predominantly downward. The water table in the tailings slopes from the north side of the tailings dam, where it is within a metre of surface, to the south side near the tailings dam, where it is approximately 10 m below surface. When they were deposited during the period from 1957 to 1968, the tailings contained pore water at a pH of about 8 resulting from neutralization treatment in the mill. At the three piezometer nests, the pH increases from 3 near the water table to 7 near the bottom of the tailings. The pore water in the tailings is gradually becoming acidic because of oxidation of pyrite in the zone above the water table. The concentrations of Fe, Mn, Ni, Co, Zn and Pb are high in the shallow acidic zone and much lower in the deeper neutral zone. Concentrations of ^{226}Ra range from 30 to 230 pCi/L. At the three sites concentrations of major ions in the permeable sand a short interval beneath the tailings indicate the presence of tailings seepage, but ^{226}Ra concentrations are only 2 to 8 pCi/L. Greater downward penetration of ^{226}Ra probably occurs in the area closer to the tailings dam.

Monitoring of a network of multilevel bundle piezometers installed in permeable sand that extends southward from beneath the tailings indicates the occurrence of a plume of tailings-derived water containing high concentrations of Ca, Mg, Fe and SO_4 that extend 400 m downgradient from the tailings dam.

The total dissolved solids decline from 20,000 at the dam to less than 500 mg/L at the identifiable downgradient periphery of the plume. A much smaller but distinct plume of water with high heavy metal concentrations and ^{226}Ra in the range of 10 to 130 pCi/L extends from beneath the dam for a distance of 15 m. The pH of the groundwater in this heavy metal-radium plume is 4 to 5, whereas elsewhere in zone of groundwater with high dissolved solids, the pH is above 6. The results of this investigation suggest that the heavy metals and ^{226}Ra are relatively immobile in the permeable sandy deposits below and beyond the tailings, except where the mobility is enhanced in zones where the pH of the groundwater has declined below about 5. In the development of predictions of the long-term subsurface movement of contaminants from the tailings, predictions of the rates and duration of pyrite adicification of tailings pore water will be necessary.

66. WATER MOVEMENT AND CONTAMINATION IN AND FROM SULPHIDE URANIUM TAILINGS RELATED TO SURFACE TREATMENT AND ABANDONMENT

by D.R. Murray - Division Report MRP/MRL 80-91(OP), August 1980.

Abstract - In the past five years an increased emphasis has been given to the path and quality of water associated with tailings material. Industry, universities and governments are attempting to understand the processes occurring when water passes onto, over, into, through and out of sulphide uranium tailings. A field lysimeter-type study was done to examine the influence of surface treatment on effluent quality and quantity. The effluent quality from tailings from which most of the pyrite has been removed is also being investigated. Laboratory lysimeters are being used to study the reaction processes and will include both saturated and unsaturated zones. A field study of the effluent plume in the ground water showed differential movement of the contaminants from the tailings. Preliminary work on a tailings profile has initiated study of the flow net pattern and the correlation between profile solid content and water content for various contaminants. These programs are beginning to come together in an attempt to create a model to better understand the problems of tailings in the context of management and abandonment.

67. EFFECT OF SURFACE TREATMENT OF TAILINGS ON EFFLUENT QUALITY

by D.R. Murray and D. Okuhara - Division Report MRP/MRL 80-92(J), 1980.

Abstract - Successful reclamation treatment, in preparation for long range abandonment of mining wastes, involves both surface treatment and water quality control containment of waste solids and liquid contaminants. This paper describes use of lysimeters containing 125 tonnes of tailings to determine the impact of gravel, sawdust and vegetation as surface treatments on the quality and quantity of effluent produced from sulphide containing uranium mill tailings. Over a five-year period these treatments were observed and compared with bare tailings where no surface addition was made.

The treatments did not alter the effluent quality to a level acceptable to regulatory requirements. Surface treatments did not appear to affect the leaching of Ra-226, NH_4 and NO_3 . The concentration of Fe, SO_4 , Cu, Pb, Al increased with the rise of acidity as the pH changed from pH 9.5 to pH 2 in four and one-half years. However the rate and extent of changes of some of these parameters varies with the treatment.

The experimental results for the observed trends are presented with limited explanation. Original design problems and unexpected delays in tailing reactions has made firm conclusions impossible at this stage.

These data, however, provide a base for further investigation and development of explanations and firm conclusions, as to the role of surface treatments in long-term waste abandonment.

68. A MODIFIED ACCUMULATOR METHOD FOR MEASURING SURFACE RADON FLUX FROM A URANIUM TAILINGS PILE

by N.K. Dave and T.P. Lim - Division Report MRP/MRL 81-85(J), 1981. Also in CIM Bull, vol. 75, No. 843, pp. 131-134, July 1982.

Abstract - A modified accumulator method was devised to measure surface radon flux from a porous media. It consists of a collector hood type accumulator with a homogenizer pump and a pressure balancer. The latter was used to compensate any pressure changes produced during sample withdrawal and hence eliminate additional radon transport from the media. Errors resulting from radon back diffusion due to decreasing concentration gradient with time across the interface were also eliminated by measuring radon concentrations in the accumulator for two different periods of time and calculating the true radon

flux, $J(o)$, from the solution of a time dependent radon transport equation in the absence of any pressure and temperature gradients.

Core samples from the observation site were also withdrawn for laboratory determination of porosity, moisture content, bulk and grain densities, Ra-226 source concentration and the fraction of Rn-222 produced in the void volume. The data were used to calculate the radon diffusion coefficient for the media.

Using the present method, the true value of surface radon flux for an abandoned uranium tailings pile was obtained as $J(o) = 2020.2 \text{ mBq/m}^2/\text{sec}$ ($54.6 \text{ pCi/m}^2/\text{sec}$) compared to the value $J = 1406.0 \text{ mBq/m}^2/\text{sec}$ ($38.0 \text{ pCi/m}^2/\text{sec}$) obtained by the conventional method. The bulk diffusion coefficient of radon for the media was obtained as $1.2 \times 10^{-7} \text{ m}^2/\text{sec}$.

69. CONTAMINANT MIGRATION IN A SAND AQUIFER NEAR AN INACTIVE URANIUM TAILINGS IMPOUNDMENT, ELLIOT LAKE, ONTARIO

by K.A. Morin, J.A. Cherry, T.P. Lim and A.J. Vivyurka - Division Report MRP/MRL 81-114(OP,J), September 1981. Also published in Can. Geotech. J., vol. 19, No. 1, pp. 49-62, 1982.

Abstract - In order to assess final abandonment schemes for and environmental impact of uranium mill tailings, an understanding of the behaviour of tailings seepage in subsurface flow systems is necessary. To advance the understanding of this behaviour, an investigation of the movement of contaminated groundwater from inactive uranium tailings through a sand aquifer is being conducted at the Nordic Main tailings impoundment near Elliot Lake, Ontario. During 1979 and 1980, a network of multilevel bundle-type piezometers was installed in the sand aquifer. Chemical analysis of groundwater samples from the piezometers indicate that a major contaminant plume extends outward through the aquifer from the southeastern part of the Nordic Main impoundment.

The source of the plume water is a section of the tailings in which pyrite has oxidized to form low-pH, high-ferrous-iron, high-sulfate water. The low-pH and high-ionic-strength condition of the water has caused the release of heavy metals and radionuclides from the solid phase into solution. This contaminated water then seeps downward through the tailings, enters an underlying glaciofluvial-sand aquifer, and flows horizontally through the sand aquifer away from the impoundment site.

In the vicinity of the contaminant plume, the sand aquifer varies in

thickness from about 9 m to 15 m. The plume has two distinct segments, referred to as the inner core and the outer zone. The inner core, which has a pH of 4.3 to 5.0 and extends about 15 m from the foot of the tailings dam, contains several thousands of milligrams per liter of iron and sulfate, and tens of picoCuries per liter of ^{226}Ra and ^{210}Pb . Water levels in piezometers within the inner core show that groundwater is moving horizontally, away from the tailings impoundment, with a velocity of several hundred metres per year. The outer zone, which surrounds the inner core near the dam and extends a few hundred metres downgradient from the dam, is characterized by hundreds to thousands of milligrams per liter of iron and sulfate, less than 15 picoCuries per liter of ^{226}Ra , and pH greater than 5.7. The small region separating the inner core and outer zone is the neutralization zone, in which all concentrations decrease from inner-core levels to outer-zone levels.

Comparison of 1979 and 1980 data shows that the front of the inner core is advancing a few metres per year, which is less than a few percent of the groundwater velocity. This retardation of movement of the inner core is caused by neutralization of the acidic water as a result of dissolution of calcium carbonate in the sand. However, mass-balance calculations using the carbonate content of the aquifer and the pH of the inner core show that the inner core is moving over two orders of magnitude faster than is predicted by simple pH neutralization by dissolution of calcium carbonate. A plausible explanation for this disagreement is the conversion of most of the calcium carbonate to ferrous carbonate (siderite). Because the neutralization zone and inner core are saturated with respect to siderite and undersaturated with respect to calcite, only calcium carbonate can dissolve to neutralize the low-pH water. Thus, replacement of calcite by siderite effectively removes most of the neutralization capacity of the aquifer, allowing the inner core to advance much more quickly.

With the rise in pH, concentrations of most contaminants are significantly reduced in solution. Mineral solubility calculations indicate that the cause of the decline in concentrations of iron and sulfate is the precipitation of siderite and gypsum, respectively. Radionuclides and trace metals are removed from solution by adsorption or coprecipitation. The hydrogeochemical mechanisms invoked in these interpretations are currently being evaluated in more detail by means of additional field measurements and by laboratory experiments as part of the on-going study of contaminant migration from the Nordic Main tailings impoundment.

70. STUDY OF RADON GAS EMANATION FROM URANIUM MINE TAILINGS AREAS - A PROGRESS REPORT

by J. Bigu, M. Grenier, N.K. Dave and T.P. Lim - Division Report MRP/MRL 82-135(OP), December 1982.

Abstract - A study of radon gas emanation and other radiation variables has been conducted at uranium tailings sites. Meteorological data such as barometric pressure, air temperature and rainfall, and soil profile data including temperature, porosity and Ra-226 content have also been measured in order to investigate the relationship of these variables with radiation data. Measurements were conducted at several depths. Results show that the radon gas concentration increases with depth and that this concentration, close to the soil surface, and the surface radon flux, are significantly affected by barometric pressure changes. These experimental observations are in agreement with theoretical expectations. The dependence of radon and radon daughter data with other variables is at present under investigation. The data reported here are part of an on-going program at Stanrock tailings aimed at investigating long-term trends in radon gas emanation from tailings piles and its radiological and environmental impact.

71. EVALUATION OF SURFACE TREATMENT TEST PITS

by D.R. Murray and H. Willett - Division Report MRP/MRL 82-148(TR), 1982.

Abstract - A study to investigate the impact of surface treatment on tailing seepage water was initiated in 1980. The report highlighted several irregularities, one of which was the reduction of seepage flow. This investigation examined the water collection system to determine the cause of seepage reduction. Tailings and chemical precipitation plugs were discovered in drain pipes and removed. Modifications were made to permit future maintenance of the free drainage.

72. GROUNDWATER FLOW PATTERN IN NORDIC WEST ARM TAILINGS AREA

by T.P. Lim, N.K. Dave and A. Vivyurka - Division Report MRP/MRL 83-34(TR), February 1983.

Abstract - Piezometers were installed in 1980 in the Nordic West Arm tailings

area to monitor the groundwater flow pattern within the tailings pile.

Contour maps of the pressure head and flow patterns were constructed from the data obtained during fall 1980, summer 1981 and spring 1982. The results indicated that the groundwater in the tailings pile flowed, in general, away from the centre of the tailings area in the east-west direction.

The eastern half of the tailings area showed an erratic flow pattern giving a non-uniform gradient distribution caused by a multi-directional inflow. The groundwater outflow from this area, therefore, could not be computed with any accuracy.

The western half of the tailings area showed a more homogeneous unidirectional flow pattern than the eastern half. Geologically, it is situated in a narrow glaciated valley, shaped like a channel, thus directing the ground-water flow westerly towards Westner Lake. Compared to the eastern half, the western half of the tailings area provided a more suitable site for calculating, with a reasonable accuracy, the groundwater outflow from the tailings area to the surrounding environment.

73. MIGRATION OF CONTAMINANTS FROM UNDERWATER BURIED URANIUM TAILINGS - LABORATORY INVESTIGATIONS OF Ra-226 TRANSFER FLUX

by N.K. Dave and T.P. Lim - Division Report MRP/MRL 83-49(OP), May 1983.

Abstract - Laboratory lysimeter tests were performed to study the migration of contaminants from underwater buried pyritic uranium tailings to the overlying water column. The tests were conducted under two conditions, a continuous flow steady-state condition and a no flow stagnant water column condition. The parameters measured with the mass transfer flux 'J', the transfer coefficient 'K' and the tailings porewater concentration 'C₀' profile as a function of depth and their variations with time for Ra-226 and total dissolved solids (TDS). The results showed that for Ra-226 all the measured parameters decreased with time with the values changing from J = 4.48 to 0.37 Bq/m²/hr (121 to 10 pCi/m²/hr), K = 0.4 to 0.18 m/month and C₀ = 9.9 to 3.9 Bq/L (267 to 105 pCi/L). From the porewater concentration profiles, a molecular diffusional component of the transport flux can be established, but it is small compared to a mass dissolution - transfer component. For total dissolved solids, the measured transfer coefficients K = 0.16 to 0.05 m/month were only one third of those obtained for Ra-226.

74. ANALYSIS OF SEASONAL VARIATIONS IN SOIL TEMPERATURE AT A URANIUM TAILINGS DISPOSAL SITE - A COMPARISON WITH THEORETICAL DATA

by M.G. Grenier and J. Bigu - Division Report MRP/MRL 83-84(TR), 1983.

Abstract - Soil temperatures in a uranium mine tailings dam were measured at regular intervals up to a depth of 5 m. The study was conducted at a tailings disposal site, 21 km northeast of the town of Elliot Lake, Ontario, between October 1982 and July 1983. The experimental soil temperature profiles were compared to simplified statistical macroclimatic models for estimating soil temperatures. At depths greater than 50 cm the model used approximated experimental temperatures within 1 or 2°C on average over a period of 10 months. In order to implement these models, meteorological variables such as air temperature, rain and snowfall were measured. The influence of snow cover on soil temperature, and the advance of the frozen front was studied. The data reported here are part of a program aimed at investigating long-term trends in radon gas emanation from tailings piles and its radiological and environmental impact.

75. STUDY OF RADON GAS CONCENTRATION, SURFACE RADON FLUX AND OTHER RADIATION VARIABLES FROM URANIUM MINE TAILINGS AREAS

by J. Bigu, M. Grenier, N. Dave, T. Lim and J. Chakravatti - Division Report MRP/MRL 83-96(J), August 1983.

Abstract - A study of radon gas concentration, surface radon flux and other radiation variables has been conducted at uranium tailings sites. Meteorological data such as barometric pressure, air temperature and rainfall, and soil profile data including temperature, porosity and Ra-226 content have also been measured in order to investigate the relationship of these variables with radiation data. Radon gas measurements were conducted at several depths and at the soil/air interface. Results show that the radon gas concentration increases with depth. However, radon which escapes to the atmosphere is limited to the boundary layer, and the pore concentration of radon in this zone is significantly affected by barometric pressure changes and other meteorological variables. These experimental observations are in qualitative agreement with theoretical expectations and with the work by other authors. Several techniques and methods were used to determine radon gas concentration and flux, and other radiation variables. The data reported here are of

interest because of the harsh environmental conditions at the location ($<-40^{\circ}\text{C}$ to $>30^{\circ}$) and are part of a research program at Stanrock tailings (Elliot Lake) aimed at investigating long-term trends in radon gas exhalation from local uranium tailings piles and its radiological and environmental impact. Measurements at just a few cm above the soil show, however, quite low radon gas concentrations and radon (thoron) daughter Working Levels.

76. RADON GAS CONCENTRATION, SURFACE RADON FLUX AND OTHER RADIATION VARIABLES FROM URANIUM MINE TAILINGS AREAS

by J. Bigu, M. Grenier, N. Dave, T. Lim and J. Chakravatti - Division Report MRP/MRL 83-104(OP,J), November 1983.

Abstract - A study of radon gas concentration, surface radon flux and other radiation variables has been conducted at uranium tailings sites. Meteorological data and soil profile data have also been measured in order to investigate the relationship of these variables with radiation data. Radon gas measurements were conducted at several depths and at the soil/air interface. Results show that the radon gas concentration increases with depth. However, radon which escapes to the atmosphere is limited to the boundary layer, and the pore concentration of radon in this zone is significantly affected by barometric pressure changes and other meteorological variables. These experimental observations are in qualitative agreement with theoretical expectations and with the work by other authors. The data reported here are of interest because of the harsh environmental conditions at the location ($>30^{\circ}\text{C}$ to $<-40^{\circ}\text{C}$) and are part of a research program at Stanrock tailings (Elliot Lake) aimed at investigating long-term trends in radon gas exhalation from local uranium tailings piles.

77. MIGRATION OF CONTAMINANTS FROM UNDERWATER BURIED URANIUM TAILINGS - LABORATORY INVESTIGATIONS OF Ra-226, TOTAL DISSOLVED SOLIDS, Ca^{+2} AND SO_4^{-2} TRANSFER FLUX

by N.K. Dave and T.P. Lim - Division Report MRP/MRL 83-105(OP,J), 1983. Also in Proc. 6th Annual Symp. on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Fort Collins, CO, February 1984, pp. 83-92.

Abstract - Laboratory lysimeter tests were performed to study the migration of

contaminants from underwater buried pyritic uranium tailings to the overlaying water column. The tests were conducted under two conditions, a continuous flow steady-state conditions and a no flow stagnant water condition. The parameters measured with the mass transfer flux 'J', the transfer coefficient 'K' and the tailings porewater concentration 'C_o' profile as a function of depth and their variations with time for Ra-226 and total dissolved solids (TDS). The results showed that for Ra-226 all the measured parameters decreased with time with the values changing from $J = 4.48$ to $0.37 \text{ Bq/m}^2/\text{h}$ (121 to $10 \text{ pCi/m}^2/\text{h}$), $k = 0.4$ to 0.18 m/month and $C_o = 9.9$ to 3.9 Bq/L (267 to 105 pCi/L). From the porewater concentration profiles, a molecular diffusional component of the transport flux can be established, but it is small compared to a mass dissolution - transfer component. For total dissolved solids, the measured transfer coefficients $K = 0.16$ to 0.05 m/month were only one third of those obtained for Ra-226. The test results from a no-flow condition indicated that the transfer coefficient 'K' for calcium ranged from 0.107 to 0.265 m/month and J_o ranged from 25.7 to $26.5 \text{ mg/m}^2/\text{h}$. Under the same conditions, the results for sulphate were $K = 0.048$ to 0.023 m/month with $J_o = 92.9$ to $98.4 \text{ mg/m}^2/\text{h}$. The variation of values obtained for the transfer coefficient 'K' for different ionic species suggested that for the two components of tailings, solid and liquid phases, different ionic species migrate differently.

78. THE USE OF A STATISTICAL MODEL FOR ESTIMATING MONTHLY SOIL TEMPERATURES IN URANIUM TAILINGS DISPOSAL SITES

by M.G. Grenier and J. Bigu - Division Report MRP/MRL 84-41(J), 1984.

Abstract - Soil temperatures were measured to a depth of 5 m at a uranium mine tailings disposal site situated 21 km northeast of the town of Elliot Lake, Ontario, between October 1982 and July 1983. The temperature profiles were compared to those obtained with a simplified statistical macroclimatic model in order to establish the reliability of such a model to predict soil temperatures in an unreclaimed tailings pond. Over a period of 10 months and at depths greater than 50 cm, the model approximated soil temperatures to within 2°C on average. The data reported here are part of a program aimed at investigating long term trends in radon gas emanations from tailings piles.

79. EFFECTS OF VARIOUS TAILINGS COVERS ON RADON GAS EMANATION FROM PYRITIC URANIUM TAILINGS

by N.K. Dave and T.P. Lim - Division Report MRL 87-84(OP,J), July 1987. Also in Proc. National Symp. on Mining, Hydrology, Sedimentology and Reclamation, Springfield, IL, December 1987, pp. 99-104.

Abstract - Radon emanation studies were carried out at an inactive pyritic uranium tailings site in Elliot Lake, Ontario, Canada, to evaluate the effects of various existing dry and wet covers on radon flux rates. Measurements were taken using activated charcoal cartridges for various surface covers consisting of bare, vegetated, acidophilic moss with high degree of water saturation, compacted crushed rock and gravel, and winter snow.

The results showed that at a given site, there was no significant difference in radon emanation rates between various tailings covers and bare tailings. In particular, no increase in radon emanation rates from vegetated areas compared to bare tailings was observed.

Radon emanation rates varied spatially depending on tailings grain size, porosity, moisture content and on pressure and water table variations. The emanation rates were higher for tailings with low water contents compared to those for wet and moss covered tailings.

80. CONSOLIDATED STRENGTH CHARACTERISTICS OF PYRITIC URANIUM TAILINGS USING: 1) POWDERED AND HYDRATED LIME IN A CARBON DIOXIDE ENVIRONMENT; 2) SLAG CEMENT.

by N.K. Dave, T.P. Lim and J.L. Chakravatti - Division Report MRL 87-93(TR), July 1987.

Abstract - Laboratory consolidation tests were carried out to evaluate in situ consolidation and strength characteristics of pyritic tailings stabilized with lime and carbon dioxide. The tailings were mixed with powdered lime, hydrated lime and blast furnace slag cement under carbon dioxide, nitrogen and air environments. The specimen samples were cured for 28 days at room temperature ($22 \pm 2^{\circ}\text{C}$) and saturated moisture conditions (100% relative humidity) and their uniaxial compressive strengths and tangent moduli of elasticity measured. The compressive strengths varied from 250 to 325 kPa for powdered lime control, 260 to 342 kPa powdered lime - CO_2 mixing, 81 to 311 kPa for hydrated lime - control, 238 to 254 hydrated lime CO_2 mixing, and 5293 to 5697

kPa for the slag cement. The tangent moduli of elasticity were measured as, respectively, 37 to 54 kPa, 30 to 44 kPa, 1 to 3 kPa, 1.7 to 3.4 kPa, and 739 to 956 MPa for the above cases. For all samples, the compressive strengths were similar for both powdered and hydrated lime samples with no significant variations among various tailing and lime ratios. For both carbon dioxide and nitrogen mixing environments, the ultimate strengths were comparable to tailings/cement and tailings/lime stabilization results and no noticeable effect of CO₂ mixing was observed. For the case of hydrated lime control samples a decrease in compressive strength with increased lime content was observed as a result of excess retained moisture (21 to 29%) after curing. The highest compressive strength and modulus of elasticity were obtained for blast furnace slag cement where the presence of aluminum oxide and silica provided additional binding and strength with the formation of hydrated aluminosilicates.

81. THE USE OF TAILINGS AS BACKFILL IN UNDERGROUND URANIUM MINES

by J. Bigu - Division Report MRL 87-106(TR), July 1987.

Abstract - Radiation field data are presented from an underground uranium mine (Denison Mines Ltd., Elliot Lake, Ontario) during and after the course of backfill operations in mined-out stopes using uranium tailings. Monitoring stations were set up at different locations during the experimental tests. Broadly speaking, an increase in the radiation level was observed from backfill material poured in some experimental stopes. The absolute contribution to the total radiation level from backfilled stopes is, however, somewhat uncertain. It should be noted that because of practical difficulties encountered during the underground tests, the data in this report should be considered of a preliminary nature, and caution should be exercised not to draw firm conclusions from the results presented.

82. MIGRATION OF ACIDIC GROUNDWATER SEEPAGE FROM URANIUM-TAILINGS IMPOUNDMENTS 1. FIELD STUDY AND CONCEPTUAL HYDROGEOCHEMICAL MODEL

by K.A. Morin, J.A. Cherry, N.K. Dave, T.P. Lim and A. Vivyurka - Division Report MRL 88-130(J), 1988. Also J. Contam. Hydrology 2:271-303, 1988.

Abstract - In this first paper of a series, the results of a study at a non-

operational tailings site are presented and are used to construct a general conceptual model for seepage migration from uranium-tailings impoundments. Many parts of the model are applicable to other types of tailings and to acid drainage in general.

At the field site, the impoundment lies over a portion of a glaciofluvial sand aquifer. Tailings seepage drains downward into the aquifer and then migrates laterally away. Results of the field study indicate the seepage can be divided into three geochemical zones: 1) the inner core, which is essentially unaltered acidic seepage from the tailings; 2) the neutralization zone, in which inner-core water is neutralized and aqueous concentrations decrease significantly; and 3) the outer zone, which contains both neutralized water from the neutralized zone and pH-neutral process water from the uranium milling operation. Yearly comparisons from 1979 to 1984 indicate the neutralization zone and inner core are migrating downgradient at a rate of about 1 m/year, which is about 1/440 of groundwater velocity. The mechanisms that produce the retardation and the decreases in aqueous concentrations are part of the conceptual model.

The main features of the conceptual model are solid-liquid interactions, particularly mineral precipitation-dissolution, and buffering effects of dominant aqueous species. The important minerals undergoing precipitation-dissolution are the calcite-siderite solid solution, gypsum, Al-OH minerals, and Fe-OH minerals. "Cell and streamtube" calculations are used to evaluate the general trends in aqueous concentrations and to assist in explaining observed migration rates. Co-precipitation with the above minerals apparently accounts for decreases in other major, minor, and metal solutes. Because of the large amount of mineral precipitation and co-precipitation, variations in ^2H and ^{18}O were observed over a flow distance of several metres, while ^{13}C remained essentially constant.

83. MIGRATION OF ACIDIC GROUNDWATER SEEPAGE FROM URANIUM-TAILINGS IMPOUNDMENTS 2. GEOCHEMICAL BEHAVIOUR OF RADIONUCLIDES IN GROUNDWATER

by K. Morin, J. Cherry, N. Dave, T. Lim and A. Vivyurka - Division Report MRL 88-131(J), 1988. Also J. Contam. Hydrology 2:305-322, 1988.

Abstract - In this second paper of a series on groundwater seepage from uranium tailings, the general geochemical behaviour of radionuclides is described and then applied to data from the field site, Seepage Area A of the

Nordic Main impoundment near Elliot Lake, Ontario. The delineation of radionuclide behaviour requires 1) the calculation of total element concentration by the summation of concentrations of each element's isotopes (the isotopic concentrations are calculated from the isotopes' radioactivities), 2) the evaluation of solid-liquid interactions using total element concentrations, and 3) for particular isotopes, the evaluation of the extent to which parental geochemical behaviour causes a deviation in the isotope's behaviour from that of its total element. A computerized speciation program, WATRAD, is used to evaluate aqueous complexation and mineral saturation indices of radium, actinium, thorium, and uranium. Data from Seepage Area A on isotopes of these four elements plus ^{210}Pb show that the geochemical behaviour of radionuclides can be best defined on an individual isotopic basis rather than on an elemental basis.

84. PARADOXICAL SECULAR DISEQUILIBRIUM OF RADIOISOTOPES IN URANIUM MINE TAILINGS

by T.P. Lim - M.Sc. Thesis, Laurentian University, Sudbury, Ontario, April 1989. Division Report MRL 89-34(OP), 1989.

Abstract - The activity ratios of daughter/parent of radioisotope species in groundwater seldom equal 1.0, indicating that isotopic disequilibrium is a common occurrence. The most common expectation of many researchers for the secular disequilibrium parameters is that this activity ratio will be less than 1.0 for parent isotopes with a very long half-life, and daughter isotopes with a very short half-life, since the activity of the daughter isotopes depends on the existence of the parent isotopes.

A review of non-mining related studies shows that activity ratios of the ^{238}U , ^{232}Th and ^{235}U decay series could differ greatly between sites, and may or may not show trends among sites. Some extreme values of activity ratios (from less than 1.0 up to 3000 with most higher than 1.0) have been observed. The review of uranium mining related studies indicates less drastic ratio values ranging from 1.0 to 241 with predominant values between 1.0 and 2.0.

The deviation of the activity ratio from the expected theoretical value of less than 1.0 (for normal secular disequilibrium) is called paradoxical secular disequilibrium.

This thesis presents an in-depth study of interactions between liquid

and solid media containing members of radioisotope decay chains, in a uranium tailings deposit. Paradoxical secular disequilibrium is seen in many of the activity ratios obtained with ratios depending on the location of the sample in the tailings pile, the nature of the isotopes involved, and the geochemical processes taking place. Laboratory experiments conducted to demonstrate the existence of paradoxical secular disequilibrium using ^{223}Ra and ^{224}Ra as natural tracers, are also described.

The importance of taking this disequilibrium into account in designing sampling and analysis procedures for systems such as a tailings area is outlined.

BIOLOGICAL PATHWAYS

85. METALS (Cu, Ni, Fe, Co, Zn, Pb) AND RADIONUCLIDE (Ra-226) LEVELS IN MEADOW VOLES (Microtus pennsylvanicus) ESTABLISHED ON REVEGETATED COPPER AND NICKEL TAILINGS IN COPPER CLIFF AND URANIUM TAILINGS IN ELLIOT LAKE

by N. Cloutier, F. Clulow, A. Vivyurka, N. Dave and T. Lim - Division Report MPR/MRL 83-53(TR), May 1983.

Abstract - Higher levels of Cu, Ni and Fe were measured in Copper Cliff tailings when compared to Elliot Lake tailings and control substrate. Elliot Lake tailings had higher levels of Pb and Ra-226 than substrate of the other two locations. Total substrate Co and Zn levels were within agricultural soil range at all three locations. Elevated levels of Ni and Fe were detected in vegetation growing on Copper Cliff tailings. Higher levels of Ra-226 were measured in vegetation growing on Elliot Lake tailings. Vegetation levels of Cu, Co and Zn did not differ between sites.

No accumulation of Cu or Co was found in meadow voles established on tailings. Ni appeared to have accumulated in livers of voles collected on Copper Cliff tailings. Elevated Fe and Zn levels were found in kidneys of Copper Cliff voles. Accumulations of Pb and Ra-226 were detected in skeletal tissues of voles established on Elliot Lake tailings.

86. RADIONUCLIDE LEVELS WITHIN VARIOUS TISSUES OF VEGETATION GROWING ON URANIUM TAILINGS IN ELLIOT LAKE

by N. Dave, T. Lim and N. Cloutier - Division Report MRP/MRL 84-5(TR), January 1984.

Abstract - Leaves, stems, flowers and seeds of creeping red fescue (Festuca rubra L.), redtop (Agrostis alba L.) and birds foot trefoil (Lotus corniculatus L.) growing on uranium tailings in Elliot Lake were analyzed for traces of radionuclides. The samples were found to contain detectable levels of Ra-226 (1.6 to 10.7 pCi/g), Pb-210 (≤ 1 to 13.2 pCi/g) and total Pb (<1.0 to 7.0 μ g/g). On the other hand, other radionuclide levels such as Th-232 (<0.1 pCi/g), Th-230 (<1.0 pCi/g), Th-228 (<0.3 pCi/g), Ra-224 (<0.1 pCi/g) as well as total radionuclide levels such as total Th (<1 μ g/g), total U (<0.2 μ g/g) were undetectable.

87. RADIONUCLIDE UPTAKE BY VARIOUS PLANTS GROWING ON URANIUM TAILINGS, ELLIOT LAKE, ONTARIO

by N. Dave, T. Lim and N. Cloutier - Division Report MRP/MRL 84-19(TR), February 1984.

Abstract - Detectable levels of Ra-226 (0.2 to 27.6 pCi/g), Ra-223 (≤ 0.1 to 4.3 pCi/g) and Pb-210 (0.6 to 6.9 pCi/g) were measured in various species of vegetation growing on various uranium tailings in Elliot Lake. On the other hand levels of Th-232 (≤ 0.1 pCi/g), Th-230 (≤ 0.1 pCi/g) and Th-228 (≤ 0.1 pCi/g) were near detection limits in the same vegetation samples. In tailings substrates, all radionuclides investigated were detectable: Ra-226 (8.8 to 552 pCi/g), Ra-223 (3.1 to 213 pCi/g), Pb-210 (5.4 to 441 pCi/g), Th-232 (1.6 to 15.4 pCi/g), Th-230 (4.9 to 62 pCi/g) and Th-228 (1.3 to 38 pCi/g).

Lower Th than Ra and Pb levels in tailings substrate were believed to be the cause for the relatively lower Th levels measured in vegetation when compared to Ra and Pb concentrations. No correlation was observed between the level of a given radionuclide in tailings and in the vegetation growing on that tailings.

88. USE OF SMALL MAMMALS FOR BIOMONITORING ENVIRONMENTAL RADIONUCLIDE LEVELS AROUND URANIUM MINING INDUSTRIES

by N. Cloutier, T. Lim and N. Dave - Division Report MRP/MRL 84-80(TR), August 1984.

Abstract - The use of small mammals for monitoring radionuclide levels in the environment near uranium tailings and open pit uranium mines is explored. The use of three species is suggested: the meadow vole for monitoring grassy habitats (i.e., revegetated tailings), and both the deer mouse and red backed mouse for monitoring forested areas) i.e., forests around open pit mines and tailings).

89. Ra-226 CONCENTRATIONS IN BLUEBERRIES (Vaccinium angustifolium Ait.) NEAR AN INACTIVE URANIUM TAILINGS SITE IN ELLIOT LAKE, ONTARIO, CANADA

N.K. Dave, T.P. Lim and N.R. Cloutier - Division Report MRP/MRL 84-95(J), July 1984.

Abstract - Ra-226 concentrations were measured in blueberries (Late Low

Blueberry, Vaccinium angustifolium Ait.) growing around the Stanrock uranium tailings area near Elliot Lake, Ontario, Canada. Elevated levels of total Ra-226 ranging between 40-165 mBq/g (dry weight) were observed in samples collected within 250 metres of the tailings (downwind). Highest levels, ~285 mBq/g, were observed in a sample collected on a tailings spill. At one site, slightly upwind and within 250 metres, intermediate levels, ~25 mBq/g, were observed. For sites located in the upwind direction and those situated at distances greater than 1 km downwind from the waste pile, the total Ra-226 concentrations approached background levels which were measured as 2-6 mBq/g. Approximately 17% of the total Ra-226 measured was removable by washing the samples with distilled water. Wind dispersal of the tailings material and its deposition in the form of dust on blueberries was believed to be responsible for the external contamination. Based on the ICRP recommended dose limits for oral intake of Ra-226, it was calculated that approximately 160 kg/a and 3350 kg/a of washed blueberries (net weight) from inside (<250 m downwind) and outside (>1 km downwind) the influenced zone would need to be consumed, respectively, before the individual annual limit for the general public was exceeded.

90. RADIONUCLIDE LEVELS IN VEGETATION GROWING ON URANIUM TAILINGS, ELLIOT LAKE, ONTARIO

N.K. Dave, N.R. Cloutier and T.P. Lim - Division Report MRP/MRL 84-104 (OP,J), November 1984.

Abstract - In Elliot Lake, Ontario, Canada, most of the inactive uranium tailings have been reclaimed by vegetation. A thick vegetation cover has been established. These surface amendments have also prompted volunteer growth of various species of local trees and shrubs on tailings. Radionuclide levels were measured in various tissues of grasses, legumes and trees growing on uranium tailings at different sites.

Leaves, stems, flowers and seeds of creeping red fescue (Festuca rubra L.), redtop (Agrostis alba L.) and birds foot trefoil (Lotus corniculatus L.) were found to contain elevated levels of Ra-226 (59 to 396 mBq/g), Pb-210 (≤ 4 to 488 mBq/g and total Pb (<1.0 to 7.0 $\mu\text{g/g}$). On the other hand other radionuclide levels such as Th-232 (<4 mBq/g), Th-230 (≤ 4 to 26 mBq/g), Th-228 (≤ 4 to 7 mBq/g), Ra-224 (≤ 4 mBq/g) as well as total Th (≤ 2.0 $\mu\text{g/g}$) and U (<0.2 $\mu\text{g/g}$) were below detection.

For various species of vegetation growing on different uranium tailings sites the radionuclide levels ranged as follows: Ra-226 (7 to 1021 mBq/g), Ra-223 (<4 to 159 mBq/g), Pb-210 (22 to 255 mBq/g), Th-232 ($\leq$ 4 to 7 mBq/g), Th-230 ($\leq$ 4 to 22 mBq/g) and Th-228 ($\leq$ 4 mBq/g). At the control sites, all radionuclide levels in the vegetation were below detection limits. In tailings substrate, radionuclide levels were measured as: Ra-226 (326 to 15133 mBq/g), Ra-223 (115 to 5717 mBq/g), Pb-210 (200 to 12961 mBq/g), Th-232 (70 to 570 mBq/g), Th-230 (181 to 1887 mBq/g) and Th-228 (48 to 1406 mBq/g).

Lower Th than Ra and Pb levels in tailings substrate were believed to be the cause for the relatively lower Th levels measured in vegetation, when compared to Ra and Pb concentrations. No correlation was observed between the level of a given radionuclide in tailings and in the vegetation growing on that tailings.

91. Ra-226 CONCENTRATIONS IN BLUEBERRIES (Vaccinium angustifolium Ait.) NEAR AN INACTIVE URANIUM TAILINGS SITE IN ELLIOT LAKE, ONTARIO, CANADA

by N.K. Dave, T.P. Lim and N.R. Cloutier - Division Report MRP/MRL 85-28 (J), February 1985.

Abstract - Ra-226 concentrations were measured in blueberries (Vaccinium angustifolium Ait., late low blueberry) growing around the Stanrock uranium tailings area near Elliot Lake, Ontario, Canada. Elevated levels of total Ra-226 ranging between 20-290 mBq/g (dry weight) were observed in samples collected within 500 m from the tailings. Highest levels, ~285 mBq/g, were observed in a sample collected on a tailings spill. For sites located more than 500 m away in the upwind direction, and those situated at distances greater than 1 km downwind from the waste pile, the total Ra-226 concentrations approached background levels which were measured as 2-6 mBq/g. Approximately 17% of the total Ra-226 measured was removable by washing the samples with distilled water. Wind dispersal of the tailings material and its deposition in the form of dust on blueberries was believed to be responsible for the external contamination. Based on the ICRP recommended dose limits for oral intake of Ra-226, it was calculated that approximately 160 kg/a, 3350 kg/a and 47 kg/a of washed blueberries (wet weight) from inside (less than 500 m), and outside (greater than 1 km downwind) the influenced zone, and from the tailings spill site (where the highest Ra-226 levels in blueberries were measured), respectively, would need to be consumed before the individual

annual limit for the general public was exceeded.

92. MIGRATION OF METALS AND TRACE RADIONUCLIDES FROM MINE TAILINGS TO THE ENVIRONMENT

by N.K. Dave, T.P. Lim and N.R. Cloutier - Division Report MRP/MRL 85-80 (OP,J), May 1985. Also in Proc. Int. Conf. on Heavy Metals in the Environment, May 1985.

Abstract - Oxidation of sulphide minerals in mine tailings results in the generation of acid which subsequently leaches and mobilizes metals and sulphate ions from tailings. Precipitation and recharge events transport these ions via surface run-off and sub-surface seepage to the surrounding environment. Neutralization of acidic porewater by the alkaline buffer within tailings and in adjacent aquifers, results in the retardation of contaminants migration. In revegetated Ni-Cu tailings, there is uptake of Ni and Fe in vegetation and Fe in kidneys and bones of resident meadow voles (Microtus pennsylvanicus). On uranium tailings, only Ra-226 is detected in vegetation and skeletons of voles.

93. METAL (Cu, Ni, Fe, Co, Zn, Pb) AND Ra-226 LEVELS IN MEADOW VOLES Microtus pennsylvanicus LIVING ON NICKEL AND URANIUM MINE TAILINGS IN ONTARIO, CANADA: ENVIRONMENTAL AND TISSUE LEVELS

by N.R. Cloutier, F.V. Clulow, T.P. Lim and N.K. Dave - Environmental Pollut. (Series B), 10:19-46, 1985.

Abstract - Copper, nickel and iron levels were higher in samples of substrate, leachate and surface water of copper-nickel mine tailings than in those from uranium mine wastes or a control area, which were similar. Nickel and iron were also elevated in the vegetation from the copper-nickel workings. The gut of resident voles was contaminated by copper and nickel and the skin and hair by nickel and iron. Higher whole body burdens of copper and nickel were attributed to the higher levels in gut and skin. Higher levels of iron observed in bone and kidney tissue were the only indications of internal deposition of these metals. Cobalt, zinc and lead levels, when detectable, in leachate vegetation and water differed little from, or were below, control levels in both tailings. Total body concentration of cobalt was lowest in animals from uranium mine tailings; their low skin contamination was due to low levels in the substrate. Total body burden of zinc did not differ among

sites. No internal deposition of cobalt was seen. Although lead levels were higher in uranium mine tailings than elsewhere, no differences were seen in lead concentrations in vegetation or resident voles. Radium-226 was detected only in the samples and voles of uranium mine wastes; the voles carried the radium-226 in their gut, skin and skeleton.

94. METAL (Cu, Ni, Fe, Co, Zn, Pb) AND Ra-226 LEVELS IN TISSUES OF MEADOW VOLES Microtus pennsylvanicus LIVING ON NICKEL AND URANIUM MINE TAILINGS IN ONTARIO, CANADA: SITE, SEX, AGE AND SEASON EFFECTS WITH CALCULATION OF AVERAGE SKELETAL RADIATION DOSE

by N.R. Cloutier, F.V. Clulow, T.P. Lim and N.K. Dave - Environ. Pollut. (Series A) 41:295-314, 1986.

Abstract - Metal (Cu, Ni, Fe, Co, Zn, Pb) and Ra-226 levels were compared in several tissues of meadow voles Microtus pennsylvanicus of both sexes and differing age groups, collected seasonally on Ni and U mine tailings and at a control site. Seasonal variation of Cu levels in liver and Fe levels in kidney was observed at all sites (Fe in liver also varied seasonally at the Ni mine site). No variation by season in metal content of muscle was observed. Small sample size from the Ni mine location did not permit a firm conclusion to be drawn regarding sex and age effects on accumulation of these metals in soft tissues. Although Co and Pb in bone did not vary by sex or age group, Pb varied seasonally. Ra-226 concentrations in bone varied by age and season but not by sex.

Levels of Ni, Co and Pb in soft tissues were below detection limits in most cases and firm conclusions on site effect could not be drawn. No site variation was observed in soft tissue levels of Cu. Fe levels of liver and kidney tissue, in summer-captured voles from tailings high in Fe, were higher than those in animals from other sites. Lowest Zn levels were seen in kidneys of voles from the site with the lowest environmental levels of the metal.

Bone content of Co did not vary by site. Skeletal Pb was highest during the summer and autumn on the uranium mine tailings while skeletal Ra-226 was highest for voles from that site during all seasons. Internal dose rate due to Ra-226 and cumulative dose at capture were calculated as 0.04 rad day⁻¹ and 2.5 rad for animals captured in the spring, 0.009 rad day⁻¹ and 0.6 rad for summer captures and 0.005 rad day⁻¹ and 0.3 rad for those taken in the autumn.

95. RADIUM-226 CONCENTRATIONS IN FAECES OF SNOWSHOE HARES, Lepus americanus, ESTABLISHED NEAR URANIUM MINE TAILINGS

by F.V. Clulow, N.R. Cloutier, N.K. Dave and T.P. Lim - J. Environ. Radioactivity, 3:305-314, 1986.

Abstract - Samples of snowshoe hare faeces were collected near revegetated and chemically stabilized uranium mine tailings and at a control site. Washing the faecal pellets in water with concurrent ultrasonic agitation was ineffective in removing all traces of external contamination. Internal ^{226}Ra levels in the faeces from the mine wastes were higher than controls. ^{226}Ra levels in faeces are considered too low to constitute an important avenue for dispersing the radionuclide from the waste site.

96. TRANSFER COEFFICIENT OF ^{226}Ra FROM VEGETATION TO MEADOW VOLES, Microtus pennsylvanicus, ON U MILL TAILINGS

by N.R. Cloutier, F.V. Clulow, T.P. Lim and N.K. Dave - Health Physics, vol. 50, No. 6, pp. 775-780, June 1986.

Abstract - The ^{226}Ra level in vegetation growing on U mine tailings in Elliot Lake, Ontario, Canada, was $211 \pm 22 \text{ mBq g}^{-1}$ (dry weight) compared to $<7 \text{ mBq g}^{-1}$ (dry weight) in material from a control site. Skeletons of meadow voles (Microtus pennsylvanicus) established on the tailings had concentrations of ^{226}Ra of $6,083 \pm 673 \text{ mBq}$ per animal in winter; $7,163 \pm 1,077 \text{ mBq}$ per animal in spring; $1,506 \pm 625 \text{ mBq}$ per animal in summer; and $703 \pm 59 \text{ mBq}$ per animal in fall, compared to $<7 \text{ mBq}$ per animal in controls. The ^{226}Ra transfer coefficient from vegetation to voles (defined as total millibecquerels of ^{226}Ra in adult vole per total millibecquerels of ^{226}Ra consumed by the vole in its lifetime) was calculated as $4.6 \pm 2.9 \times 10^{-2}$ in summer and $2.8 \pm 0.6 \times 10^{-2}$ in fall.

97. UPTAKE OF ^{226}Ra BY ESTABLISHED VEGETATION AND BLACK CUTWORM LARVAE, Agrotis ipsilon (Class Insecta: Order Lepidoptera), ON U MILL TAILINGS AT ELLIOT LAKE, CANADA

by F.V. Clulow, N.K. Dave, T.P. Lim and N.R. Cloutier - Health Physics, vol. 55, No. 1, pp. 31-35, July 1988.

Abstract - Radium-226 levels in samples from an inactive U tailings site at

Elliot Lake, Ontario, Canada, were: $9,140 \pm 500 \text{ mBq g}^{-1}$ dry weight in the substrate; $62 \pm 1 \text{ mBq g}^{-1}$ dry weight in rye, Secale cereale, and $<3.7 \text{ mBq g}^{-1}$ dry weight in oats, Avena sativa, the dominant species established by revegetation of the tailings; and $117 \pm 7 \text{ mBq g}^{-1}$ dry weight in washed and unwashed black cutworm larvae. Concentration ratios were: vegetation to tailings 0.001-0.007; black cutworms to vegetation 3.6 and black cutworms to tailings 0.01. The values are considered too low to be considered a hazard to herring gulls, Larus argentatus, which occasionally feed on cutworms.

98. TRANSFER COEFFICIENT OF ^{226}Ra FROM FOOD TO YOUNG WEANED MEADOW VOLES, Microtus pennsylvanicus, IN THE LABORATORY

by B. Burns, F.V. Clulow, N.R. Cloutier, N.K. Dave and T.P. Lim - Health Physics, vol 52, No. 2, pp. 207-211, Feb. 1987.

Abstract - In a recent study, we reported transfer coefficients of ^{226}Ra from vegetation to meadow voles (Microtus pennsylvanicus) established on U mill tailings, of 4.6×10^{-2} in summer-trapped animals and 2.8×10^{-2} in fall trapped specimens. These values were based in part on the assumption that the observed skeletal ^{226}Ra levels of mature adults at the time of capture were entirely due to the dietary intake of the radionuclide after weaning. It was not possible to separate dietary, lactation, or other age-dependent contributions to the observed data on field skeletons. The calculated transfer coefficients thus represent upper limits. It is known that alkaline earth series radionuclides, such as ^{90}Sr and ^{226}Ra , being analogous to Ca, are bone seekers and lodge principally in the skeleton where they replace Ca and show a marked age dependence during the rapid bone development period. To supplement the field results for voles, and to elucidate the various assumptions made, a laboratory investigation was made of the various transfer pathway components. We report here a study of the transfer of ^{226}Ra from food to meadow voles during the 30 days immediately following weaning.

99. Ra-226 CONCENTRATIONS IN OTTER, Lutra canadensis, TRAPPED NEAR URANIUM TAILINGS AT ELLIOT LAKE, ONTARIO

by C.D. Wren, N.R. Cloutier, T.P. Lim and N.K. Dave - Bull. Environ. Contam. Toxicol. 38:209-212, 1987.

Abstract - Canada has a significant uranium mining industry which will likely continue to expand in the future. Exploitation of uranium ores has produced large quantities of surface waste tailings near mine sites. The Elliot Lake area of Ontario, is currently the major uranium producing region of Canada. It is estimated there are 120 million tonnes of uranium tailings spread over 600 ha in the vicinity of Elliot Lake. Many inactive tailing sites have been stabilized either chemically or through revegetation.

The transfer and fate of uranium-series radionuclides from tailing sites remain primary ecological concerns in these areas. It has been demonstrated that the levels of radionuclides, including Ra-226, are elevated in vegetation, small mammals and fish living on or near tailing disposal sites. However, the transfer potential of Ra-226 to predatory species has not been examined in detail. The objective of this study was to measure Ra-226 levels in otters (Lutra canadensis), captured near tailing sites, to provide further information on the fate of radionuclides in the environment.

100. RADIUM-226 IN SNOWSHOE HARES NEAR URANIUM MINE TAILINGS

by F.V. Clulow, N.R. Cloutier, N.K. Dave and T.P. Lim - Division Report MRL 89- (TR), 1989.

Abstract - Snowshoe hares (Lepus americanus) trapped near uranium tailings accumulated ^{226}Ra in their bone to levels ($275 \pm 94 \text{ mBq.g}^{-1} \text{ d.w.}$) approximately ten times higher than those from areas 3-15 km from the mines; these in turn were at least five times higher than in hares from an area 880 km away. Most stomach contents had levels of ^{226}Ra below detection limits ($3.7 \text{ mBq.g}^{-1} \text{ d.w.}$). This precluded calculation of the transfer coefficient from food to hare. Based on the levels of ^{226}Ra in bones, the maximum internal dose rate to the skeleton and the maximum lifetime dose of hares living near tailings were $3.2 \times 10^{-5} \text{ Gy.d}^{-1}$ and 3.5×10^{-2} respectively. These levels are not thought to pose a health hazard either to the animals or consumers.

101. SKELETON BURDEN OF RADIONUCLIDES (Th-230, Ra-226, Pb-210, Po-210, Th-232, Th-228) AND TOTAL U AND Th IN SNOWSHOE HARES NEAR URANIUM MINE TAILINGS.

by F.V. Clulow, N.K. Dave, T.P. Lim and N.R. Cloutier, submitted for publication Health Physics - Division Report MRP 89- (J), 1989.

Abstract - Snowshoe hares (Lepus americanus) trapped near uranium tailings showed elevated levels of Ra-226 in their bones ($250 \pm 94 \text{ mBq.g}^{-1}$ dry weight), compared to $20\text{--}30 \text{ mBq.g}^{-1}$ d.w. at local control sites (3-15 km from tailings sites) and less than 3.7 mBq.g^{-1} d.w. at a distant control site located 880 km away from uranium mining areas. Elevated levels of Pb-210 and Po-210 ($95\text{--}245 \text{ mBq.g}^{-1}$ d.w.) were observed at all sites suggesting higher intake at non-tailings sites. No significant accumulation of U, Th and its isotopes were observed at any site. Higher levels of Th-228 compared to Th-232 are attributed to accumulation of Ra-228 similar to that of Ra-226. Most stomach contents had levels of Ra-226 below detection limits (3.7 mBq.g^{-1} d.w.). Based on the levels of Ra-226 and Po-210 in bones, the maximum internal dose rate to the skeleton and the maximum lifetime dose of hares living near tailings were $3.9 \times 10^{-5} \text{ Gy.d}^{-1}$ and $4.2 \times 10^{-2} \text{ Gy}$, respectively. These levels are believed to be too low to produce osteosarcoma in hares or contribute significantly to environmental transport of radionuclides from tailings.

102. RADIONUCLIDE LEVELS AND ^{226}Ra CONCENTRATION RATIOS BETWEEN WATER, VEGETATION AND TISSUES OF RUFFED GROUSE (Bonasa umbellus) FROM A WATERSHED WITH U TAILINGS NEAR ELLIOT LAKE, CANADA

F.V. Clulow, T.P. Lim and N.K. Dave, submitted for publication to Environmental Pollution - Division Report MRL 89- (J), 1989.

Abstract - Radionuclide levels measured in bone, muscle, kidney and liver tissues, gut contents, and diet items of 47 grouse from the Serpent River drainage basin, containing U tailings at Elliot Lake, and from control areas in Ontario, showed variation by site and tissue.

The mean level of ^{226}Ra in bones of grouse sampled from Elliot Lake (28.5 mBq.g^{-1}) was higher than that in bones of birds from a distant control site near Sudbury, Ontario (8.0 mBq.g^{-1}) but similar to the value in a local control population (28.1 mBq.g^{-1}). Birds from Mid- and Low-Serpent River basin populations (with 17.1 and 17.7 mBq.g^{-1} respectively) did not differ from local or distant control populations; muscle, liver, and kidney had lower ^{226}Ra concentrations which did not differ significantly among

populations. Levels of ^{226}Ra in the crop contents and chyle did not differ significantly by site and were similar to those of food items consumed by the birds. Chyme values were higher in birds sampled in Elliot Lake and at the local control site than in those taken at the distant control site; birds sampled downstream from Elliot Lake did not differ from distant controls in this regard.

Levels of ^{232}Th , ^{230}Th were below detection limits ($0.1 \mu\text{g.g}^{-1}$ and 5.0mBq.g^{-1} respectively) in bone, muscle, and liver tissue in two grouse with elevated levels of ^{226}Ra . Other radionuclides were measurable in some tissues: U-238 in bone at $0.4 \mu\text{g.g}^{-1}$, in muscle to $0.2 \mu\text{g.g}^{-1}$, in liver to $1.0 \mu\text{g.g}^{-1}$; Th-228 was found only in muscle (8.0mBq.g^{-1}); Po-210 was found in bone, muscle, and liver (maxima 24.0, 7.0, 16.0mBq.g^{-1}) with the exception of one muscle sample; Pb-210 was detected in only one liver sample (50.0mBq.g^{-1}). Radionuclides were considered to be in secular equilibrium.

Environmental levels fell within ranges previously reported at the sites, or at similar locations elsewhere. Leaves of trembling and largetooth aspen growing in the basin had mean ^{226}Ra levels of 41.8 and 52.7mBq.g^{-1} (dry weight) respectively, fungal material carried up to 215.4mBq.g^{-1} (air-dried), with some variation by site. River and lake waters sampled near the U tailings had 118.1mBq.l^{-1} of dissolved ^{226}Ra , and at the distant control site the value was 12.1mBq.l^{-1} .

The concentration ratios (CR) between trembling and largetooth aspen leaves and bone of grouse collected at the Elliot Lake sites were 1.38 and 1.09 (fresh weight basis); from other diet items and to other tissues the values were less than unity. Water to tissue bone ratios, based on dissolved ^{226}Ra levels (mBq.l^{-1}) ranged to 144.08.

People eating grouse from the study area are unlikely to consume radionuclides in excess of limits currently established by Canadian regulatory authorities.

103. RADIONUCLIDES IN WATER, VEGETATION, AND TISSUES OF BEAVER (Castor canadensis) FROM A WATERSHED CONTAINING U TAILINGS NEAR ELLIOT LAKE, CANADA, WITH CALCULATION OF ^{226}Ra CONCENTRATION RATIOS

F.V. Clulow, M.A. Mirka, N.K. Dave and T.P. Lim, submitted for publication to Environmental Pollution - Division Report MRL 89- (J), 1989.

Abstract - Radionuclide levels were measured in tissues, gut contents, and diet items of adult beaver from the Serpent River drainage basin which contains U tailings at Elliot Lake, and from control sites in Ontario.

Levels of ^{226}Ra in beaver bone, muscle, and kidney were highest in animals from locations close to U tailings; liver levels did not vary by site. Environmental ^{226}Ra levels were within ranges previously reported at these or similar locations elsewhere; levels in beaver gut contents reflected levels in diet items. Concentration ratios exceeded unity only between some vegetation items and beaver bone at the Elliot Lake site and were less than 0.19 between vegetation and other tissues.

In two beaver with tissue levels of ^{226}Ra higher than others sampled, neither ^{232}Th nor ^{230}Th were detected in bone, muscle, and liver; Th-228 and Pb-210 were measurable only in bone. Estimated yearly intakes of radionuclides by people eating beaver were calculated to be below current allowable levels set by Canadian regulatory authorities.

The beaver is judged unsuitable as an indicator (biomonitor) of environmental radionuclide contamination as correlation between bone and ambient (water) levels of ^{226}Ra is low.

104. Ra-226 IN CATTAILS (*Typha latifolia*) AND BONE OF MUSKRAT (*Ondatra zibethica*) FROM A WATERSHED WITH U TAILINGS NEAR ELLIOT LAKE, WITH CALCULATION OF CONCENTRATION RATIO

M.A. Mirka, F.V. Clulow, N.K. Dave and T.P. Lim, submitted for publication to Environmental Pollution - Division Report MRP 89- (J), 1989.

Abstract - Radionuclide levels were measured in bone and diet items of adult muskrat from the Serpent River drainage basin which contains U tailings at Elliot Lake, and from control sites in Ontario. Muskrat from waters with mean total ^{226}Ra levels in the period 1984-1987 of 111.0 mBq.l^{-1} or more, near U tailings at Elliot Lake, Ontario, Canada, had a mean bone ^{226}Ra level of 468.0 mBq.g^{-1} (dry weight, $n = 30$), those from nearby waters with less than 111.0 mBq.l^{-1} had a mean bone level (61.5 mBq.g^{-1} , $n = 11$) similar to that of animals taken in uncontaminated local control areas 20 km from the tailings (92.8 mBq.g^{-1} , $n = 16$); animals from a control area at Sudbury, 130 km distant, had the lowest mean burden (11.5 mBq.g^{-1} , $n = 24$). Levels were unrelated to age or sex of the animals.

Ra-226 levels in the main plant eaten by muskrat (cattail, *Typha*

latifolia) varied by plant part and place of collection. Roots sampled in the contaminated area had the highest mean ^{226}Ra level ($1,135.0 \text{ mBq.g}^{-1}$, stems and leaves had 284.2 and 275.9 mBq.g^{-1} respectively ($n = 6$ in all cases). Radium-226 levels in cattails generally declined with increasing distance of sample location from Elliot Lake. Cattails from the local control locations had a mean level of ^{226}Ra of 20.0 mBq.g^{-1} ; distant control samples had 15.1 mBq.g^{-1} (weighted average).

Concentration ratios between dietary items (plant parts) and bone of muskrat taken at Elliot Lake-high sites were calculated (fresh weight basis) to range from 1.1 to 8.5. These were similar to values calculated for humans. Transfer parameters were relatively low from diet to muskrat bone and it seems unlikely that adverse effects accrue to animals living on the Elliot Lake U tailings.

The muskrat is judged to be a useful indicator (biomonitor) of environmental radionuclide contamination as correlation between bone and ambient (water) levels of ^{226}Ra is high. Estimated yearly intakes of radionuclides by people eating muskrat were calculated to be below current allowable levels set by Canadian regulatory authorities.

ANALYTICAL/INSTRUMENTATION

105. RAPID ANALYSIS OF URANIUM MILL EFFLUENTS USING SPECIFIC-ION ELECTRODES

by D. Moffett - Report MRP/MRL 76-60(OP), April 1976.

Abstract - Increasingly stringent government regulations on the level of contaminants in mill effluents necessitates large numbers of routine chemical analyses. Specific-ion electrodes hold some promise in simplifying the analysis for some species, and their use in the determination of ammonia, nitrate, and sulphate is discussed with examples from an acid-leach uranium mill in the Elliot Lake area. The applicability of a copper electrode in the analysis of effluents is examined as a typical example of a specific-ion metal electrode.

106. SOME APPLICATIONS OF SPECIFIC-ION ELECTRODES IN THE MINING INDUSTRY

by D. Moffett - Report MRP/MRL 77-93(J), March 1977.

Abstract - Increasingly stringent government regulations on the level of contaminants in mill effluents necessitates large numbers of routine chemical analyses. Specific-ion electrodes hold some promise in simplifying the analysis for some species. The use of specific-ion electrodes in the determination of ammonia and nitrate in effluents was investigated, using an acid-leach uranium-oxide mill effluent from the Elliot Lake area. The nitrate electrode was also used for process control within the mill and it provided acceptable results while speeding-up the analysis. The ammonia electrode was applied to the determination of the cation-exchange capacity of the vegetated tailings, and provided useful data on the rate of soil development.

Finally, a potentiometric determination of sulphate using a lead electrode was made on dust-sample filters from diesel exhausts. This gave a rapid and precise analysis of the sulphuric acid content of the exhausts.

107. MULTI PURPOSE TESTER FOR MEASURING SIMULTANEOUSLY ENGINEERING AND RADIATION PROPERTIES OF RADIOACTIVE HYDRAULIC BACKFILLS, WASTE MATERIALS AND URANIUM ORES.

by V. de Korompay - Report MRP/MRL 78-83(TR), September 1978.

Abstract - A multi purpose instrument has been developed for measuring some of the physical properties of materials such as radioactive hydraulic backfills,

waste materials and uranium ores, without removing or repacking the unconsolidated samples during the testing procedure.

The instrument is basically the combination of a porosity meter, air and water permeameter, water saturator, water saturation meter and an open and closed emanation chamber. Special features of the instrument are: a) it measures simultaneously the engineering and radiation properties of the material; b) it eliminates the effect of the rising and falling barometer during testing; c) it measures the effect of the rising and falling barometer on the emanation rate; d) air samples can be taken from the closed emanation chamber without changing the original pressure in it; e) the tester can simulate selected underground mining conditions.

The practical application of the tester has indicated that it is a useful tool for the laboratory investigation of radioactive backfills and water materials.

108. PROPOSED PROCEDURE FOR USING A 'HYDRAULIC POT' FOR MEASURING THE EFFECT OF THE REVEGETATION ON THE HYDRAULIC AND RADIATION CONDITIONS OF URANIUM TAILINGS PONDS

by V. de Korompay - Report MRP/MRL 79-65(OP,J), April 1979.

Abstract - The so-called 'Hydraulic Pot' has been developed to measure the effect of the revegetation on the hydraulic and radiation properties of uranium mill tailings stored in surface ponds.

The 'Hydraulic Pot' is basically the combination of a seeding pot, a multifunctional hydraulic tester and an open radon collector hood.

The instrument permits the measurement of the physical properties of the tailings during the growing of the vegetation planted in the pot.

109. DILUTION GAUGING METHOD USING CHLORIDE AND IODIDE SELECTRODE FOR TAILING EFFLUENT DISCHARGE MEASUREMENT

by T. Lim - Report MRP/MRL 79-78(TR), July 1979.

Abstract - An accurate, fast, reliable and economical means of stream flow measurement using selectrodes based on the dilution gauging method has been developed at Elliot Lake Laboratory. A chloride tracer and its ion selectrode are used.

An iodide tracer, which has a lower background concentration than chloride in nature and its selectrode, whose sensitivity is 12.570 times better than the chloride selectrode can be used for a wider range of operations.

An approximation for selecting tracer concentration and injection flow rate is given.

An homogeneity comparison test to establish the sampling point and assure complete mixing is described in this paper.

110. THE EFFECT OF FILTER SIZE ON Ra-226 WATER SAMPLES FROM EFFLUENT DISCHARGE by T.P. Lim - Division Report MRP/MRL 80-46(TR). March 1980.

Abstract - A methodology for obtaining representative water samples from surface effluent discharge originating from an abandoned uranium tailing needs to be improved. The basic philosophy of water sampling is discussed. Different sizes of filter were used, based on the nature of the problem.

A test was designed to examine the difference in Ra-226 concentration of the filtrate by using different sizes of Millipore filters, 0.3 μm , 0.45 μm , 0.8 μm , 1.2 μm , 3.0 μm and 8.0 μm in succession. The results indicated no significant difference of concentration when using filters between 0.3 μm to 8.0 μm for this particular stream.

A hypothetical size distribution and further investigation for Canada-wide operation is suggested in this report.

This is part of the project to develop methods to reduce the detrimental environmental effects of inactive tailings piles with regard to volume and quality of seepage.

111. A RAPID METHOD OF Ra-226 ANALYSIS IN WATER SAMPLES USING AN ALPHA SPECTROSCOPIC TECHNIQUE

by T.P. Lim and N.K. Dave - Division Report MRP/MRL 80-52(OP,J). Jan. 1980

Abstract - A fast, reliable and accurate method for Ra-226 determination in environmental water samples has been devised, using an alpha spectroscopic technique. The correlation between Ba-133 and Ra-226 in the Ba-Ra sulphate precipitation mechanism was studied and in the limited experimental recovery

range, the coefficient of correlation was $r = 0.986$. A self-absorption study for various Ba carrier concentrations was also undertaken to obtain the least broadening of alpha energy line widths. An optimum value of 0.3 mg Ba carrier concentration was obtained for chemical recovery in the range of 85%.

112. FIELD SAMPLE MANAGEMENT REPORT

by T.P. Lim, P. Milewski, Y. Sleyphen and M. Turcotte - Division Report MRP/MRL 81-14(TR), January 1981.

Abstract - The purpose of this report is to present a summary and projection of work to date. The National Planning Board and Tailings Project Administration will thereby become familiar with difficulties encountered in our work.

An assessment of current difficulties has yielded a number of suggestions for immediate implementation on current work. The nature of Tailings Project 4.3.0.6.01.01 necessitates the procurement of a large volume of samples and data. The main problems encountered to date are a shortage of manpower and equipment. The following suggestions are made: a) the addition of 1 laboratory technician; b) the addition of 2 field technicians; c) the acquisition of an atomic absorption spectrophotometer; d) access to a computer with three dimensional graphing facilities with CRT display; e) additional storage facilities.

The information contained in this report may be used as a guideline for future projects, particularly an expansion to include Beaverlodge and Cluff Lake sites.

113. A RAPID METHOD OF RADIUM-226 ANALYSIS IN WATER SAMPLES USING AN ALPHA SPECTROSCOPIC TECHNIQUE (REVISION OF MRP/MRL 80-52(OP,J))

by T.P. Lim and N.K. Dave - Division Report 81-84(J), January 1980. Also in CIM Bulletin, vol. 75, No. 833, pp. 97-105, September 1981.

Abstract - A fast, reliable and accurate method for radium-226 determination in environmental water samples has been devised, using an alpha spectroscopic technique. The correlation between barium-133 and radium-226 in the barium-radium sulphate precipitation mechanism was studied and in the limited experimental recovery range, the coefficient of correlation was $r = 0.986$. A

self-absorption study for various barium carrier concentrations was also undertaken to obtain the least broadening of alpha energy line widths. An optimum value of 0.3 mg barium carrier was obtained for chemical recovery in the range of 85%.

114. A COAXIAL GROUNDWATER SAMPLING PUMP FOR NARROW DIAMETER DEEP PIEZOMETERS

by N.K. Dave, T.P. Lim and J. Smith - Division Report MRP/MRL 82-12(J), January 1982.

Abstract - A coaxial groundwater sampling pump using CPVC plastic pipes with double check valves is designed for narrow diameter deep piezometers to obtain representative water samples for geochemical investigations. The pump is hand operated and relatively inexpensive to build. It was field tested in a 15 m deep, 3.2 cm diameter piezometer and delivered approximately 100 mL of sample per stroke.

115. DESIGN AND INSTALLATION OF RUGGED THERMOCOUPLES FOR USE IN CORROSIVE TAILINGS

by M. Grenier and D. Murray - Division Report MRP/MRL 82-121(INT), 1982.

Abstract - Copper-constantan thermocouples were designed and constructed to monitor the temperature at various depths in acidic mine tailings during radon emanation studies. The components required to build these thermocouples are available off the shelf. The thermocouples were placed into tailings up to a depth of 5 metres. The method used to install deep probing thermocouples was to drill a 2.5 cm diameter hole to the required depth, placing the thermocouple in the hole, then partially filling the hole with fine sand, leaving the top 30 cm to be filled with bentonite to seal the thermocouple in place.

116. PERFORMANCE TEST OF SPECTRASpan V SEQUENTIAL ATOMIC EMISSION SPECTROMETER

by T.P. Lim, N. Cloutier, Y. Boucher and N. Dave - Division Report MRP/MRL 85-47(TR), March 1985.

Abstract - The stability and performance test of 'Spectraspan V' - high energy

direct current plasma emission sequential spectrometer, was conducted.

The instrument was very stable against electronic and thermal drift components. The plasma stability of the system was very sensitive to sample introduction, electrode configuration and nebulizer pressure. At 28 psi (193 kPa) nebulizer pressure, the stability of the system lasted for over an hour compared to about 15 min at 24 psi (166 kPa) pressure. Regression analysis of the calibration data showed expected linearity of 95% confidence limit.

117. HIGH RESOLUTION ALPHA-SPECTROMETRY FOR RADIUM ANALYSIS - THE EFFECTS OF SAMPLE THICKNESS AND FILTER PORE SIZE

by T.P. Lim, N.K. Dave and N.R. Cloutier - Division Report M&ET, MRL 87-12 (J), November 1986. Also in Int. J. App. Radiation & Isotopes, vol. 40, No. 1, pp. 63-76, 1989.

Abstract - In the α -spectrometric technique for radium isotope analysis, the effects of the barium carrier thickness and pore size of the membrane filter (used for the main Ba-Ra sulphates filtration) on the resolution of the α -energy peaks were investigated. With 0.45 μ m Millipore filters, the full width at half maximum (FWHM) for 4.78 MeV α -decay peak of Ra-226 decreased from 221.7 keV to 121.3 keV with reduction in barium carrier additions from 320 μ g to 20 μ g Ba. The resolution further improved to 74.5 keV for 20 μ g Ba carrier when 0.2 μ m Nucleopore filters were used. There was also a significant decrease (20-50%) in the retention of radon and its daughters compared to their equilibrium concentrations as the barium carrier thickness was reduced.

A correlation study between Ba-133 tracer and Ra-226 isotopes recovery factors gave a recovery factor Ra-226/Ba-133 ratio of 0.93 ± 0.08 in the main Ba-Ra sulphate precipitate under various pH and sulphate concentration conditions.

118. HIGH RESOLUTION ALPHA-SPECTROMETRY FOR RADIUM ANALYSIS - THE EFFECTS OF SAMPLE THICKNESS AND FILTER PORE SIZE (REVISION OF M&ET/MRL 87-12(J))

by T.P. Lim, N.K. Dave and N.R. Cloutier - Division Report MRL 88-15(J), March 1988.

Abstract - In the alpha-particle spectrometric technique for radium isotope analysis, the effects of the barium carrier thickness and pore size of the

membrane filter (used for the main Ba-Ra sulphate filtration) on the resolution of the α -particle energy peaks were investigated. With 0.45 μm Millipore membrane filters, the full width at half maximum (FWHM) for 4.78 MeV alpha-decay peak of Ra-226 decreased from 221.7 keV to 121.3 keV with reduction in barium carrier additions from 320 μg to 20 μg Ba. The resolution further improved to 67.0 keV for 20 μg Ba carrier when 0.2 μm Nucleopore filters were used. There was also a significant decrease (20-50%) in the retention of radon and its daughters compared to their equilibrium concentrations as the barium carrier thickness was reduced.

A correlation study between Ba-133 tracer and Ra-226 isotopes recovery factors gave a recovery factor Ra-226/Ba-133 ratio of 0.93 ± 0.08 in the main Ba-Ra sulphate precipitate under various pH and sulphate concentration conditions.
